A Recirculating Linac-based Facility for Femtosecond X-ray Pulses

W. Barry, J. Byrd, J. N. Corlett, S. DeSantis, M. A. Green, N. Hartman, P. Heimann, E. Kujawski, D. Li, R. McClure, H. Padmore, I. Reichel, R. Rimmer, K. Robinson, R. Schoenlein, J. Tanabe, D. Truchlikova, W. Wan, S. Wang, R. Wells, A. Zholents

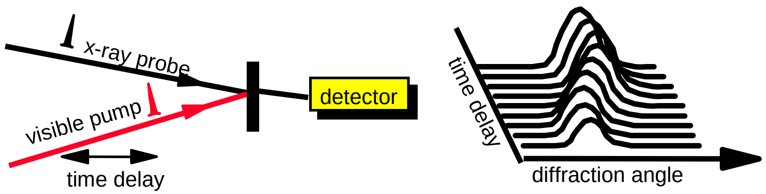
Accelerator and Fusion Research Division
Advanced Light Source Division
Engineering Division
Materials Science Division
Facilities Division

CBP Seminar
June 2002

Strong scientific case for time resolved experiments at timescales of the order of atomic vibrational period $1\ \text{Å}/v_{sound} \sim 100$ fs

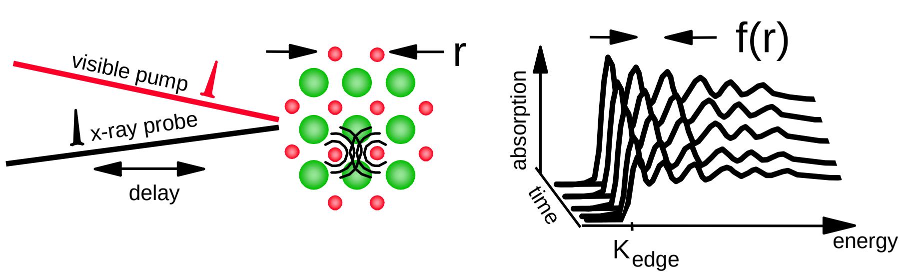
- **Ultrafast structural dynamics in solids**
  - Order/disorder transitions (melting)
  - Solid-solid phase transitions
  - Surfaces
- **Ultrafast molecular dynamics**
  - Structural dynamics of the transition state
  - Solvent/solute interactions (solvent structure)
- **Ultrafast processes in biology**
- **Atomic and molecular physics**
- **Magnetization and spin dynamics**
- **Dynamics in warm dense matter**

Time-resolved x-ray diffraction



Ordered crystals - phase transitions, coherent phonons

Time-resolved EXAFS, NEXAFS, surface EXAFS



Complex/disordered materials - chemical reactions
surface dynamics
bonding geometry

Science is broad-based and emergent

Workshop on New Opportunities in Ultrafast Science using X-rays

April 14-17, 2002, in Napa, CA

The development of ultrafast optical laser systems has revolutionized the study of many problems in the biological, chemical, and physical sciences. The advent of ultrafast x-ray sources offers the possibility for extending optical studies to include x-ray techniques such as x-ray absorption spectroscopy (to give local chemical and magnetic information) and x-ray diffraction (to give structural information), with time resolution to well below 100 fsec. This workshop aimed to bring together the existing ultrafast optical community and the emerging ultrafast x-ray community in order to define scientific highlights and directions for the use of the x-ray techniques, to promote cross fertilization of ideas between the two communities, and to define the source characteristics required for particular classes of experiment. The time regime from 50 psec to a few 10's of fsec was the core area for this workshop.

Agenda

- *with links to abstracts*

Abstracts of Poster Presentations

- *with links to abstracts*

Attendance List

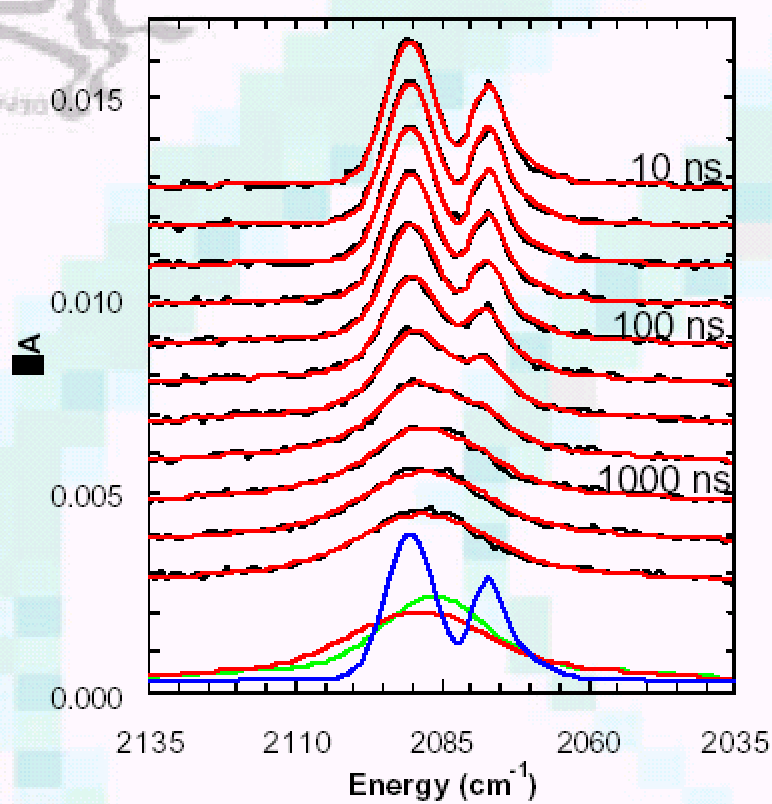
Local Organizing Committee

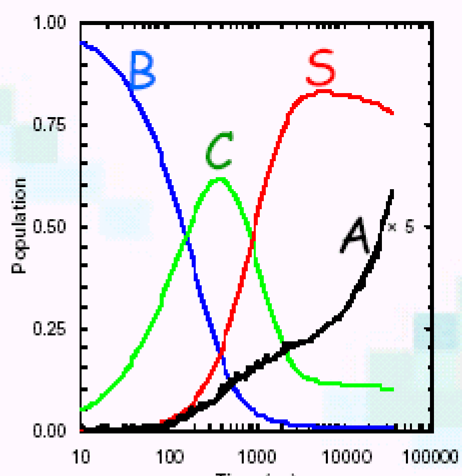
Yves Petroff (LBNL)
Bob Schoenlein (LBNL)
Ernie Glover (LBNL)
Roger Falcone (U. California, Berkeley)
Phil Heimann (LBNL)
Howard Padmore (LBNL)
Andreas Scholl (LBNL)
Joachim Stohr (SSRL)
John Arthur (SSRL)
Jerry Hastings (SSRL)

Program Committee

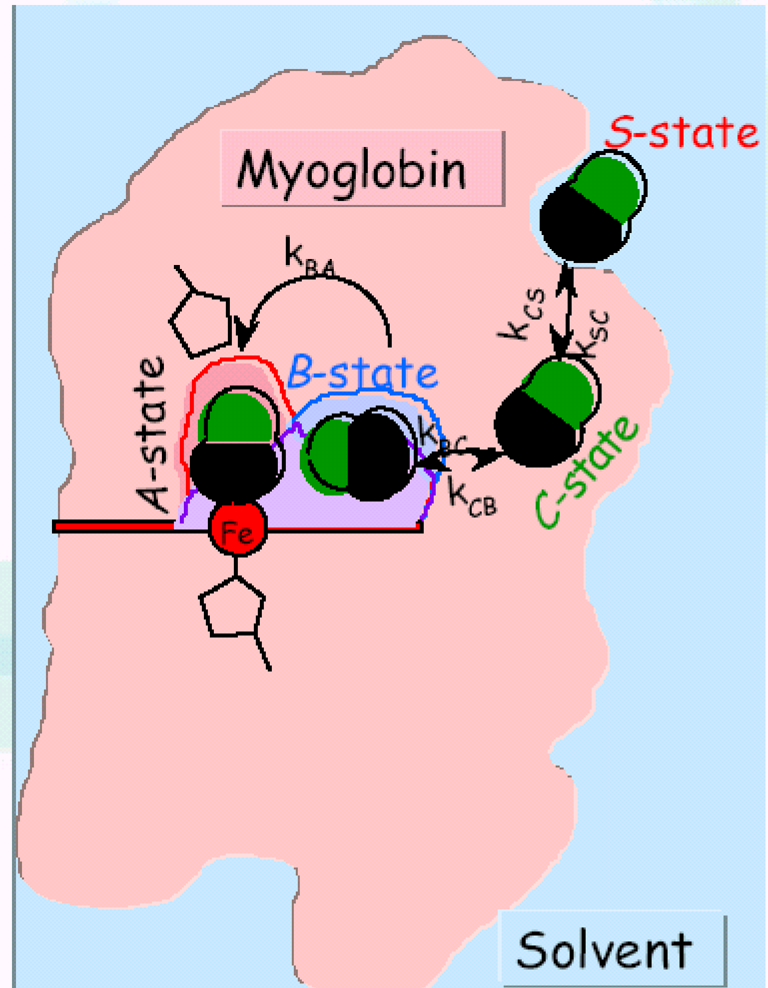
R. Abella (SLS)
P. Bucksbaum (U. Michigan)
P. Corkum (Steacie Institute, Ottawa)
W. Eberhardt (BESSY, Juelich)
R. Falcone (U. California, Berkeley)
C. Harris (U. California, Berkeley)
R. Hochstrasser (U. Pennsylvania)
G. Materlik (Diamond, RAL)
K. Moffat (U. Chicago)
M. Murnane (JILA U. Colorado)
K. Nelson (MIT)
C. Shank (UCB / LBNL)
H. Siegmann (Stanford/SSRL)
J. Stohr (Stanford / SSRL)

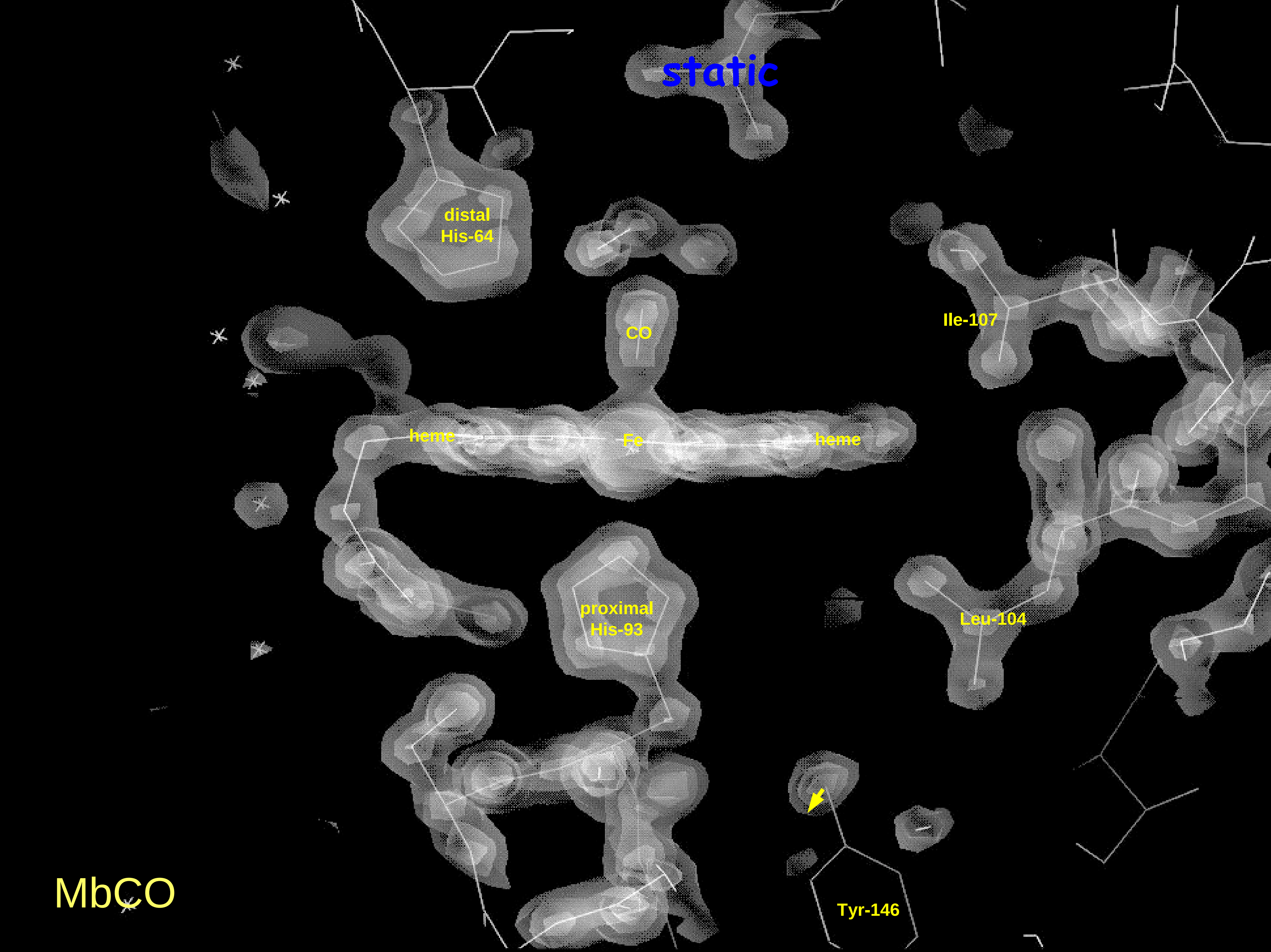
Ligand *Dynamics in Myoglobin* (*h*-Mb^{13}CO in D$_2$O @ 10.4 °C



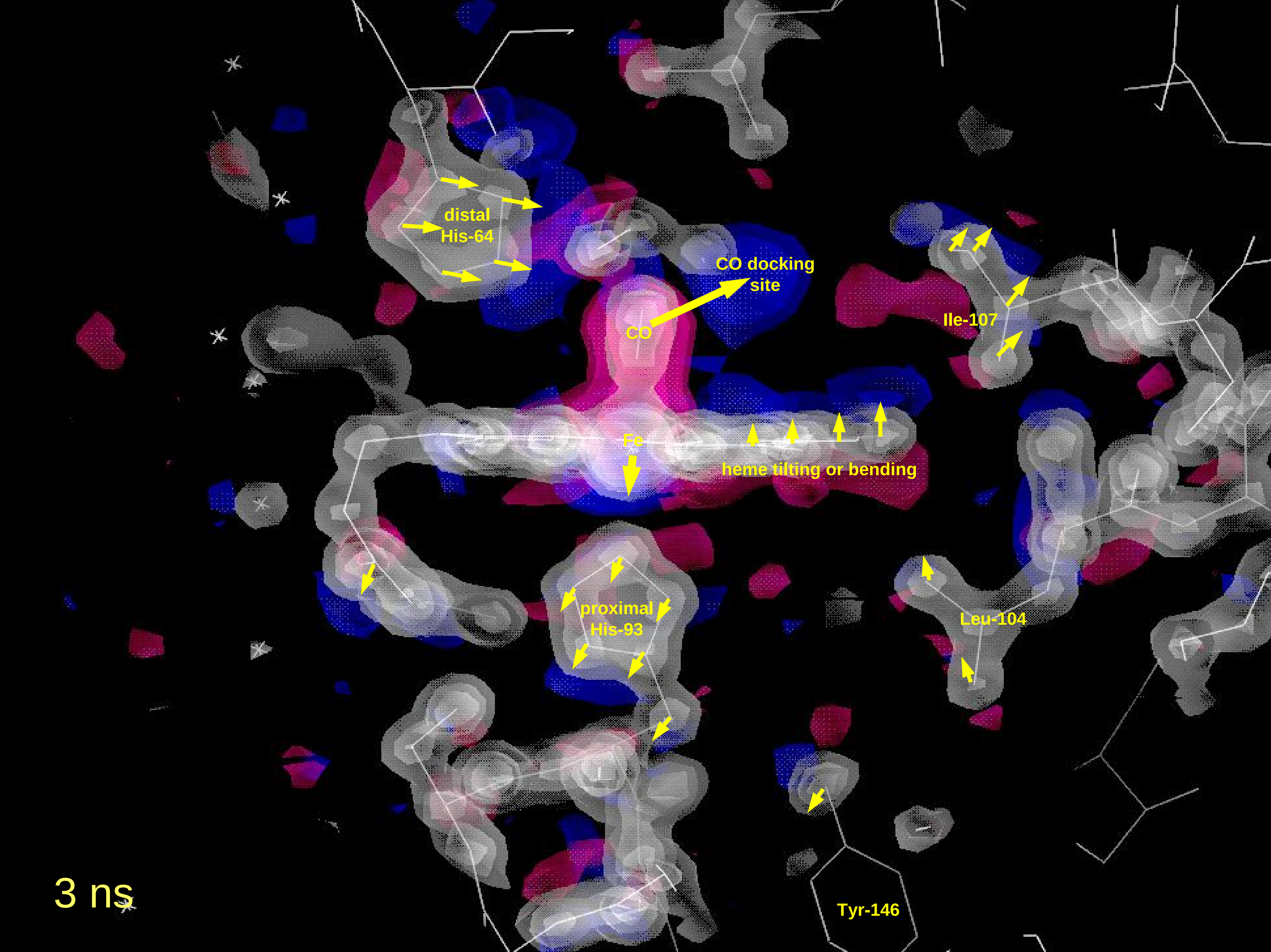


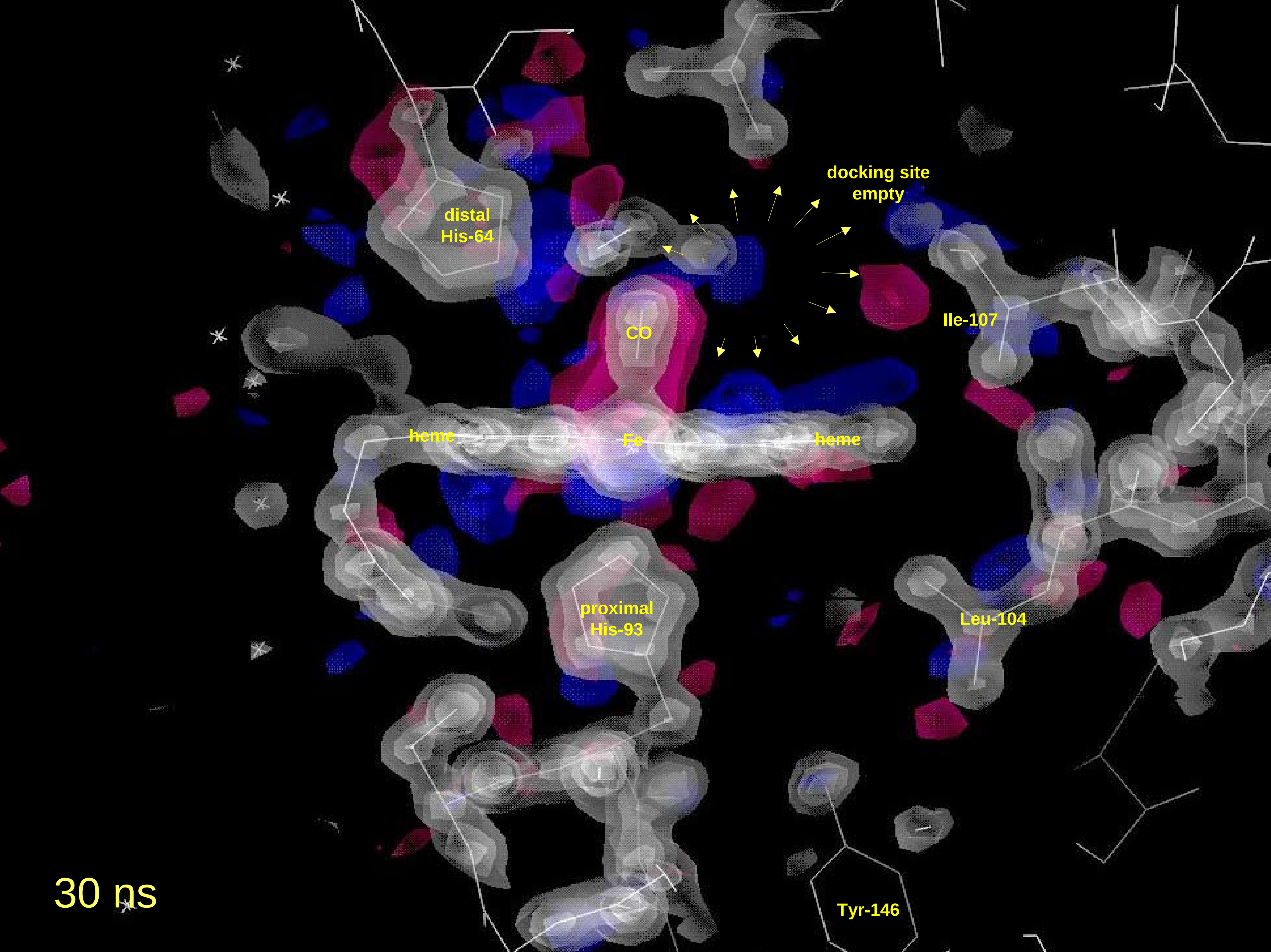
$$A \xleftarrow{k_{BA}(t)} B \underset{k_{CB}}{\overset{k_{BC}}{\rightleftharpoons}} C \underset{k_{SC}}{\overset{k_{CS}}{\rightleftharpoons}} S$$





static
distal
His-64
CO
Ile-107
heme
Fe
heme
proximal
His-93
Leu-104
Tyr-146
MbCO


distal
His-64
CO docking
site
CO
Ile-107
Fe
heme tilting or bending
proximal
His-93
Leu-104
Tyr-146
3 ns



docking site
empty
distal
His-64
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Ile-107
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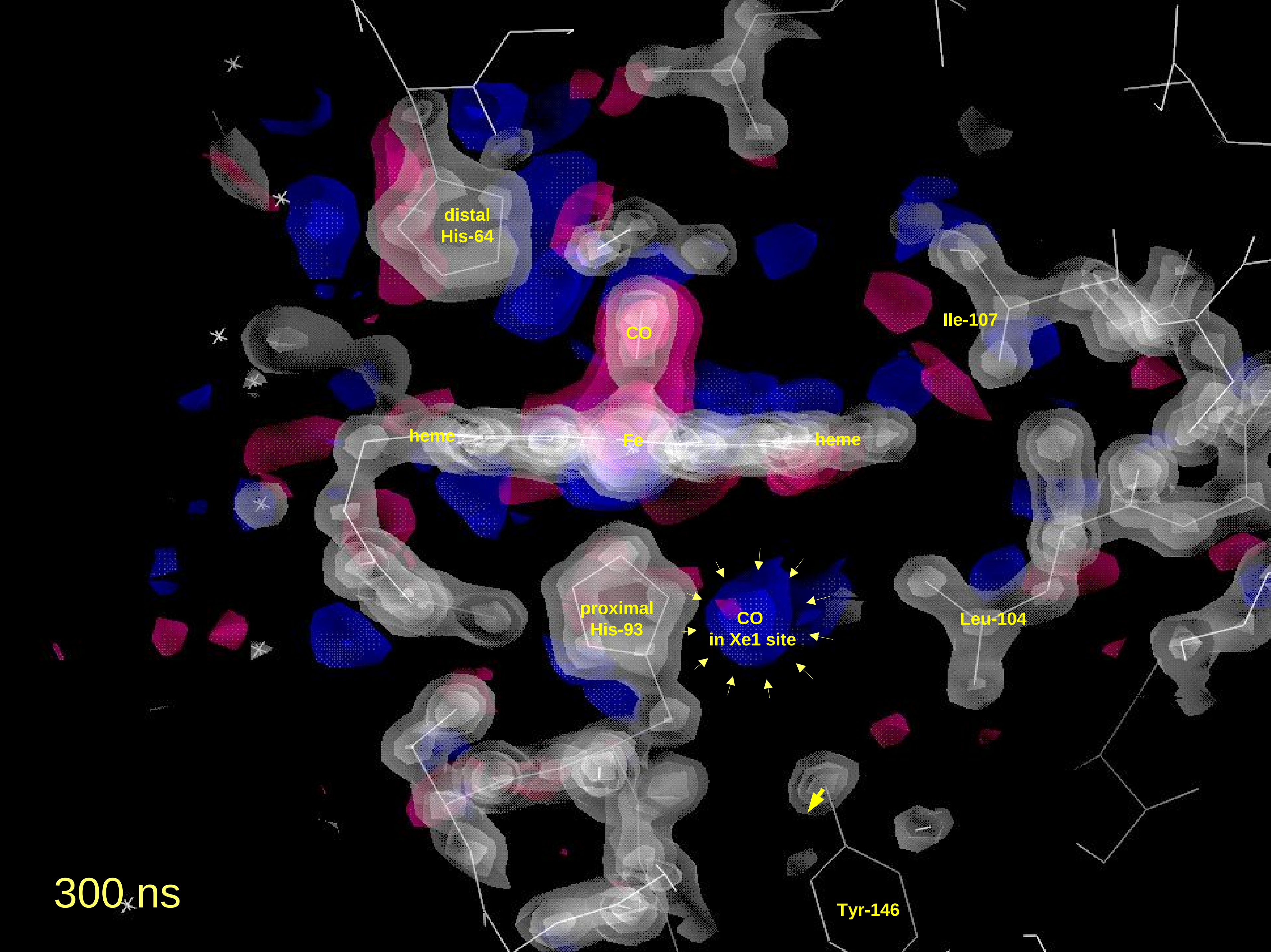
proximal
His-93
Leu-104
Tyr-146
30 ns


distal
His-64
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His-93
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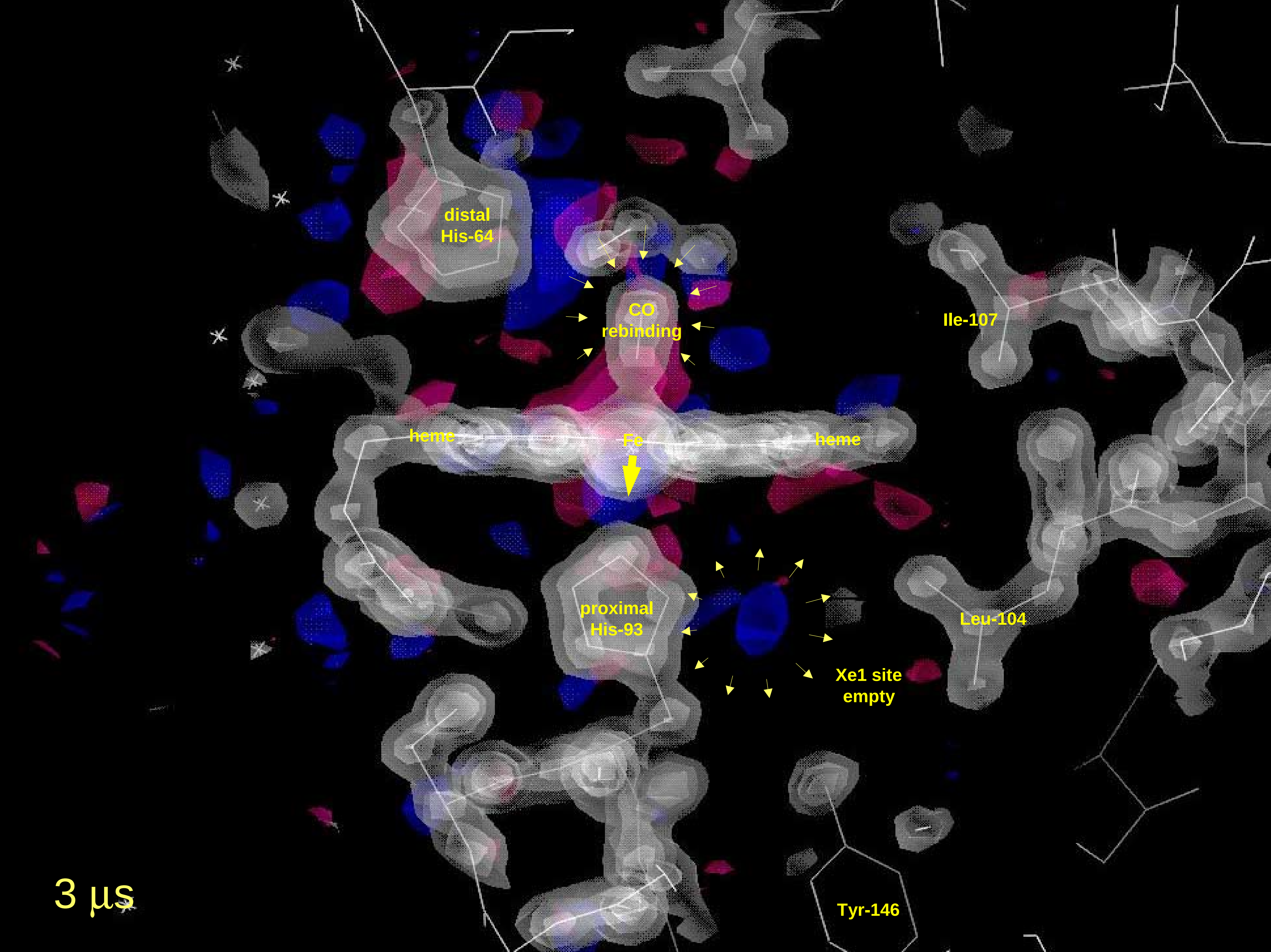
in Xe1 site
Leu-104
Tyr-146
300 ns


distal
His-64
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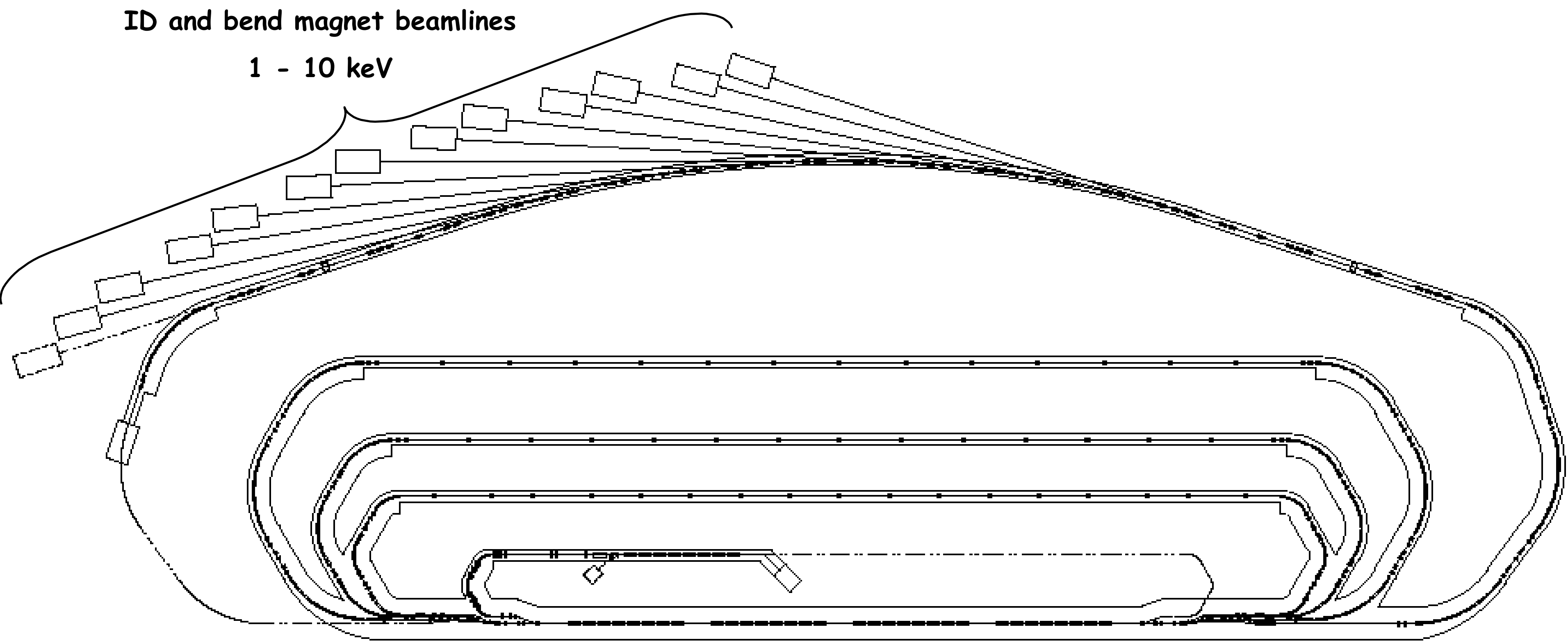
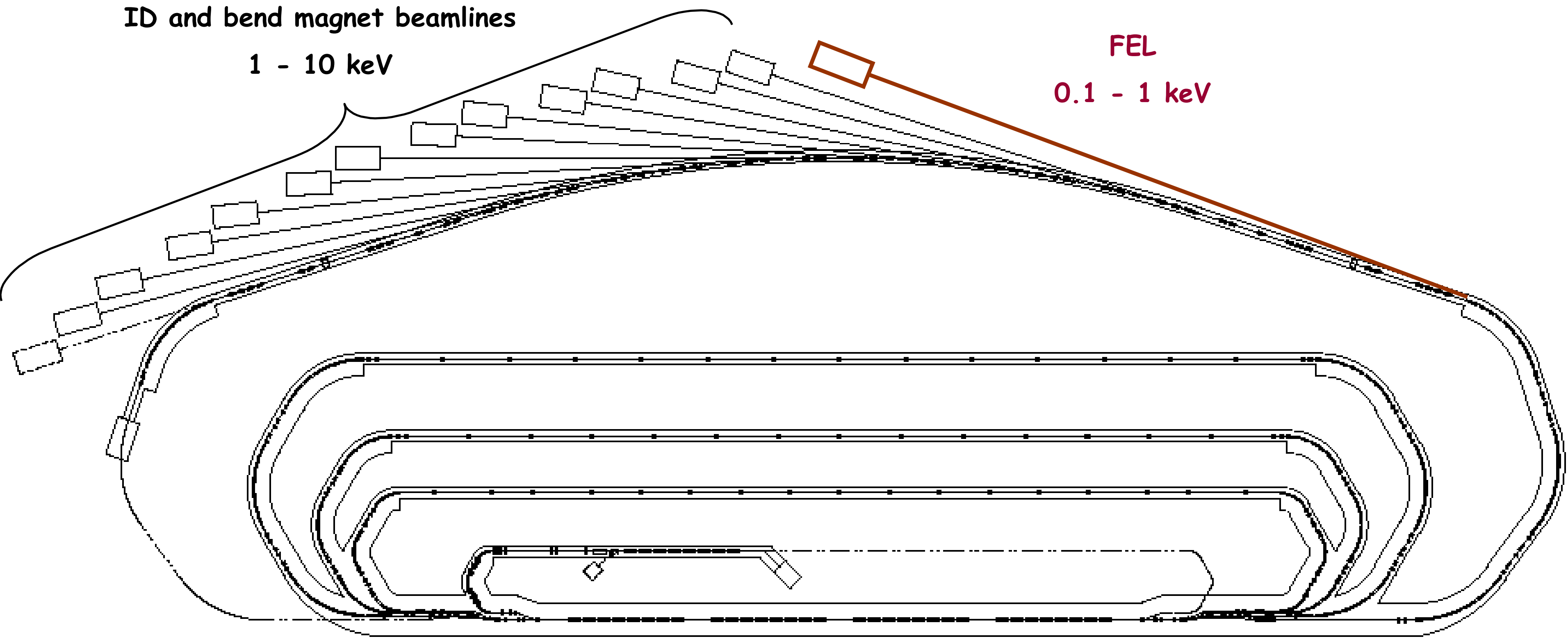
heme
proximal
His-93
Leu-104
Xe1 site
empty
Tyr-146
3 µs

An ultra-fast x-ray user facility driven by scientific needs in Physics, Chemistry and Biology



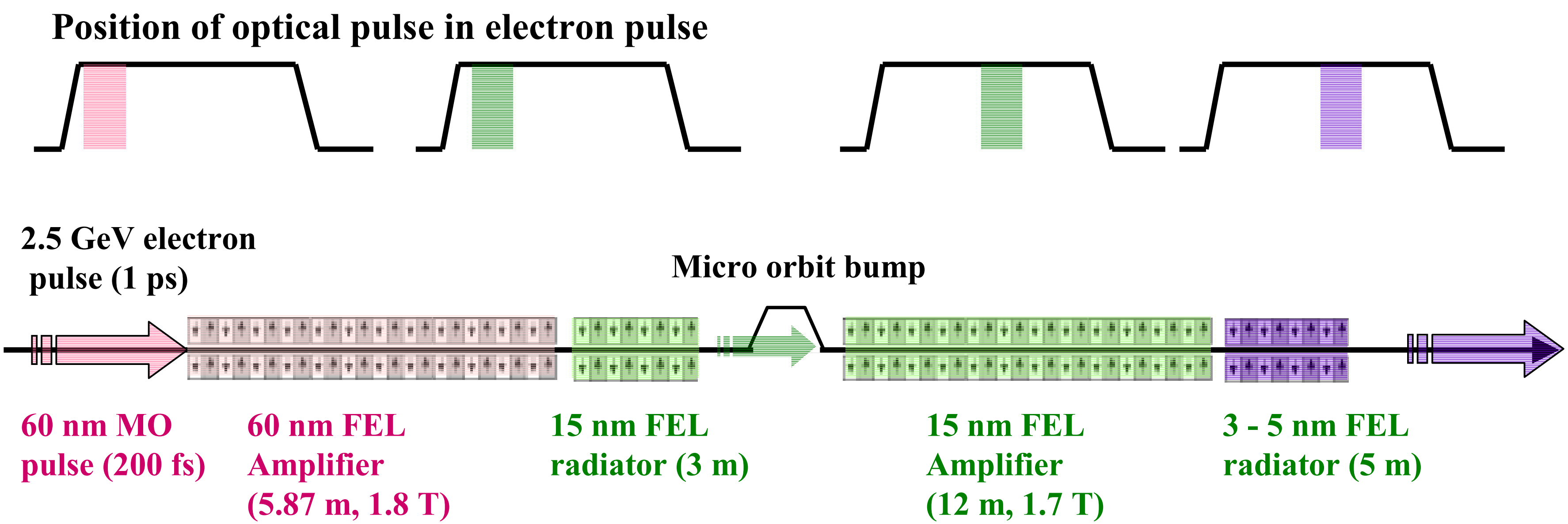
- Baseline parameters:
  - Short X-ray pulse <100 fsec FWHM at 10 keV
  - Repetition rate 10 kHz
  - High flux 10^7 photons/pulse/0.1%BW at 10 keV
  - Tunable photon energy 1 - 10 keV
  - Synchronization ~ 10 fs

Soft X-ray FEL
extends photon range below 1 keV



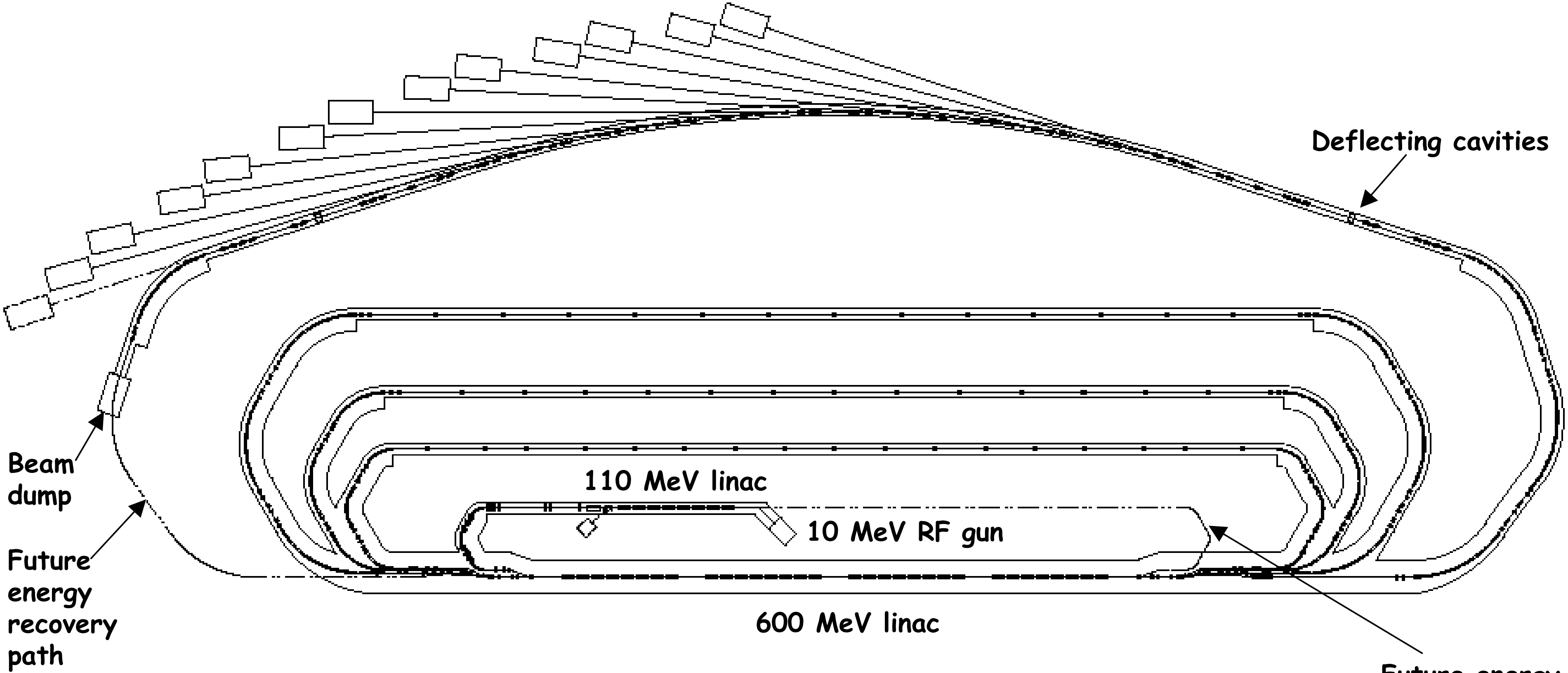
- FEL
  - Takes advantage of available high quality beam
  - ~ 0.1-1 keV
  - Variable up to ~ 10^{12} photons per pulse in 0.1% bw
  - 200 fs pulse
  - Synchronized

High-gain harmonic generation soft X-ray FEL



FEL scheme for generation of precisely timed pulses of
10^8 - 10^{12} photons/pulse over range of 15 - 3 nm

Machine operation



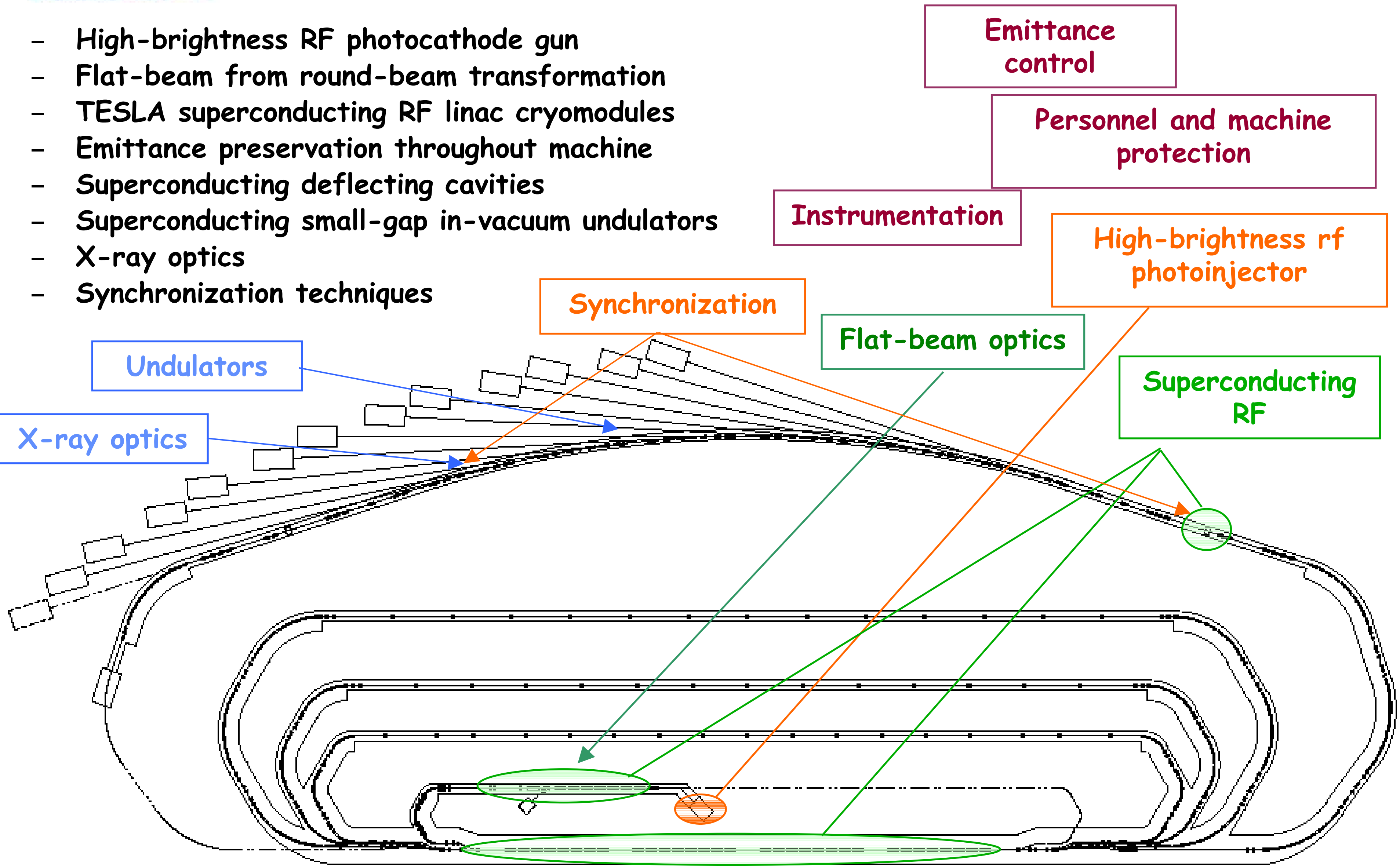
- Generate ~ nC bunch in RF photocathode
- Produce small vertical emittance from round beam
- Accelerate to ~ 100 MeV
- Inject into, followed by four passes through, 600 MeV linac
- Produce time / angle correlation within bunch
- Radiate in insertion devices and bend magnets
- Compress x-ray pulse from ps scale to 50 fs scale

Baseline beam power 25 kw

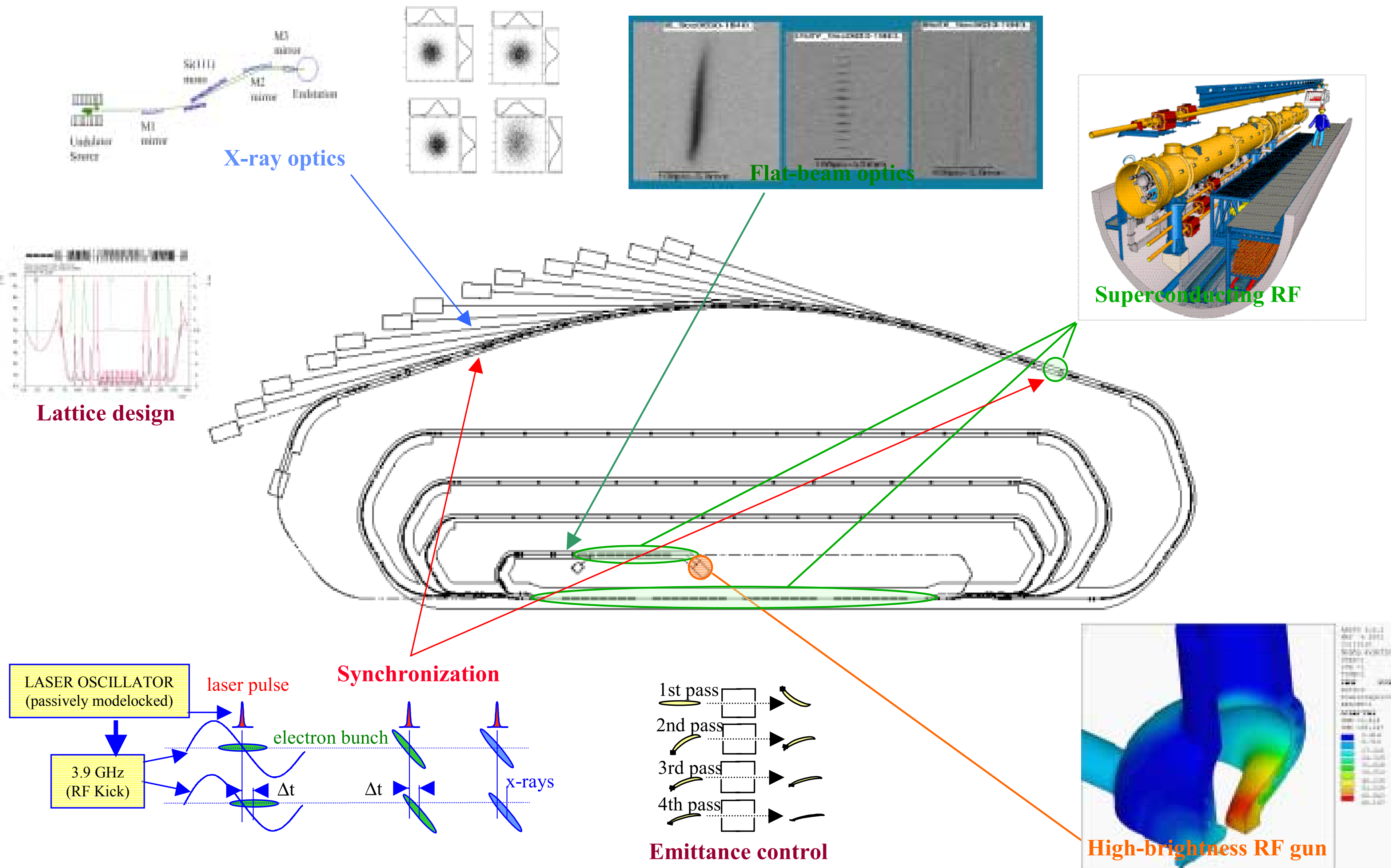
Use energy recovery for beam power above ~ 100 kW

Machine utilizes progress in key technologies
Technical challenges identified and prioritized

- High-brightness RF photocathode gun
- Flat-beam from round-beam transformation
- TESLA superconducting RF linac cryomodules
- Emittance preservation throughout machine
- Superconducting deflecting cavities
- Superconducting small-gap in-vacuum undulators
- X-ray optics
- Synchronization techniques

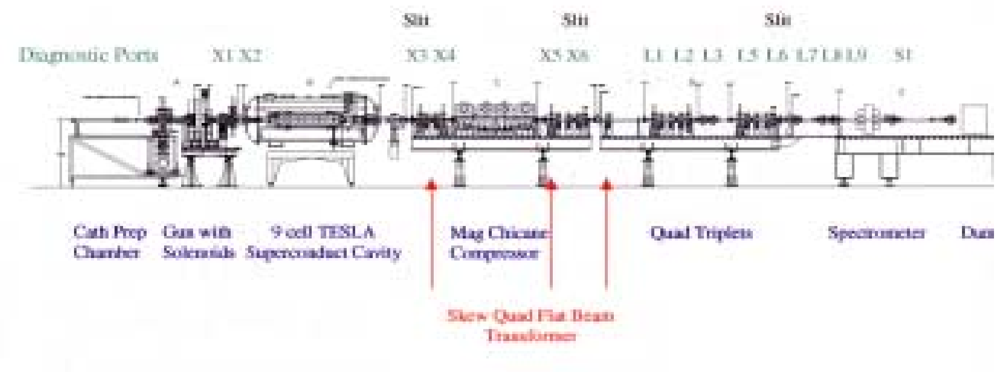


Challenges in accelerator physics and technologies

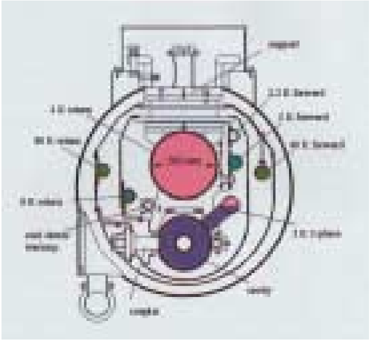


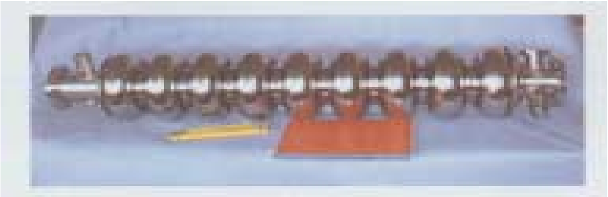
Collaborations in key technologies

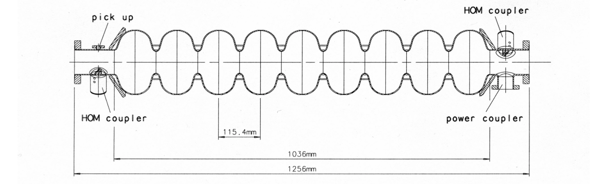
- Fermilab A0/NICADD facility
  - High-brightness RF photocathode gun
  - Flat-beam from round-beam transformation



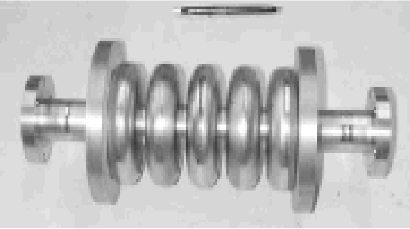
- DESY
  - TESLA superconducting RF
  - Linac cryomodules
  - Superconducting RF systems
- TJNAF
  - Superconducting RF systems







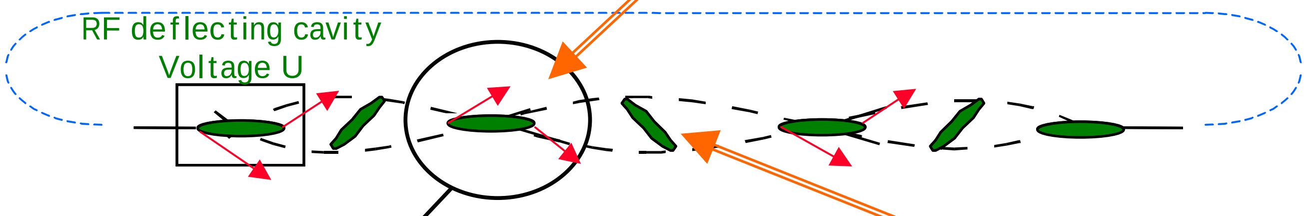
- Fermilab
  - Superconducting deflecting cavities



Femtosecond x-ray pulses from picosecond bunches Reduces problems associated with ultra-short electron bunches

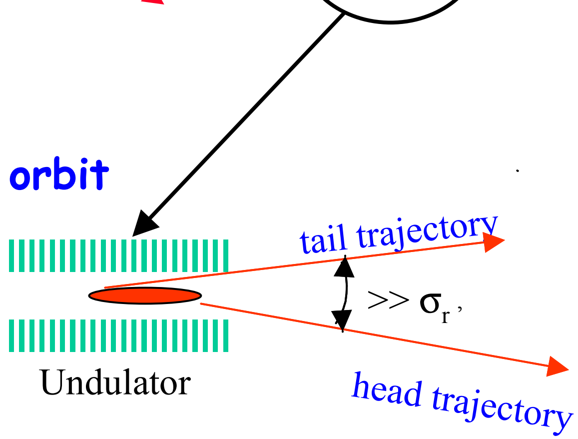
- **Deflecting cavity introduces angle-time correlation into the ~ ps electron bunch**

$$\delta y'(z) = \frac{eU}{E_{beam}} \sqrt{\frac{\beta_{cavity}}{\beta_{ID}}} \sin(k_{rf} z)$$



$$\delta y(z) = \frac{eU}{E_{beam}} \sqrt{\beta_{cavity}\, \beta_{bend}} \sin(k_{rf} z)$$

- **Electrons oscillate along the orbit**



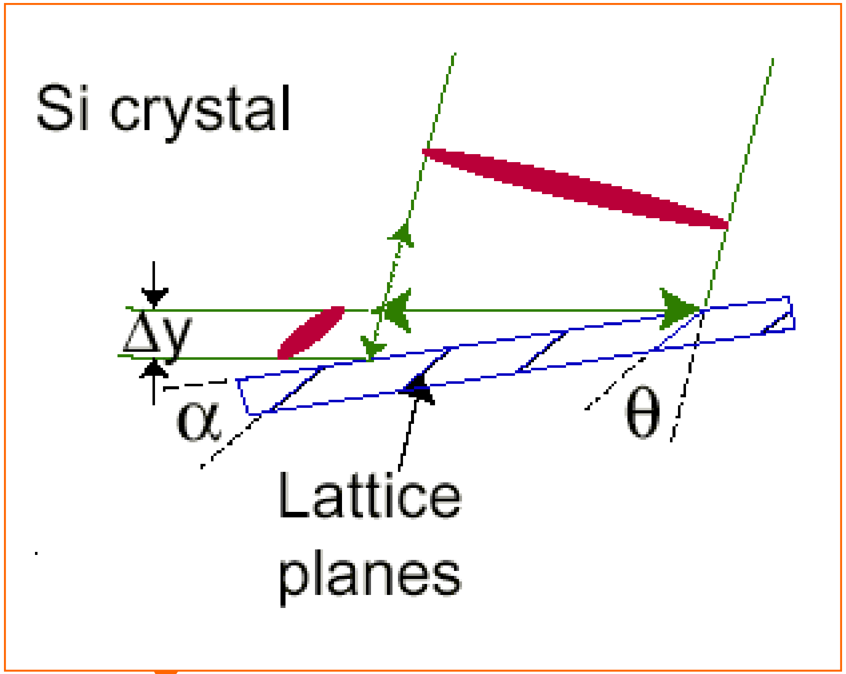
Bunch tilt ~ 140 μ-rad (rms)

Radiation opening angle ~ 7 μ-rad @ 1Å

- **Crystal x-ray optics take advantage of the position-time correlation, or angle-time correlation to compress the pulse**

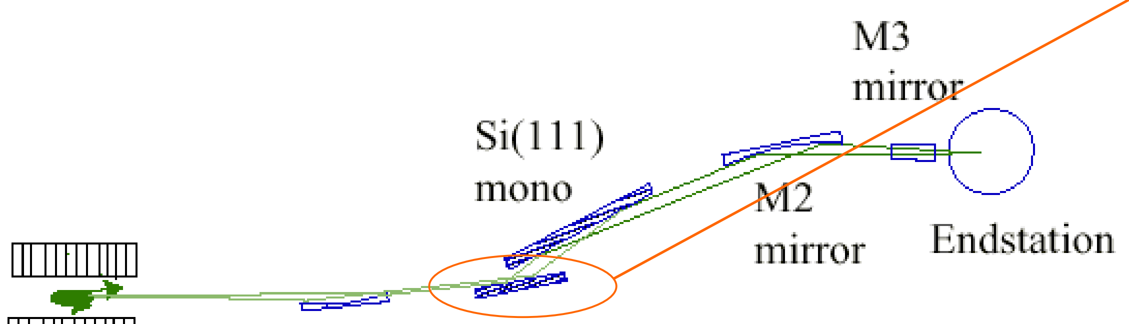
Femtosecond x-ray pulses from picosecond bunches - x-ray compression

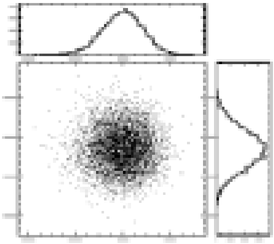
- Optical path length Δl varies linearly with position Δy on crystal
- We propose to use a pair of asymmetrically cut silicon crystals following collection optics



$$\Delta l = 2\,\Delta y \frac{\sin\theta\ \sin\alpha}{\sin(\theta+\alpha)}$$

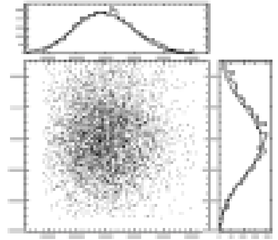
	λ	2Y	θ	α	2L
Si(111)	1.5 Å	1.5 mm	14.309°	2.1°	0.3 mm





Focus dimensions

20μm (h) x 12 μm (v)



Focus divergence

1.2 mrad (h) x 500 μrad (v)

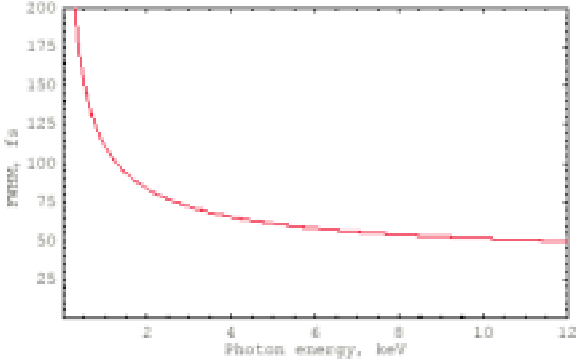
X-ray pulse duration

Bend magnet x-ray pulse duration

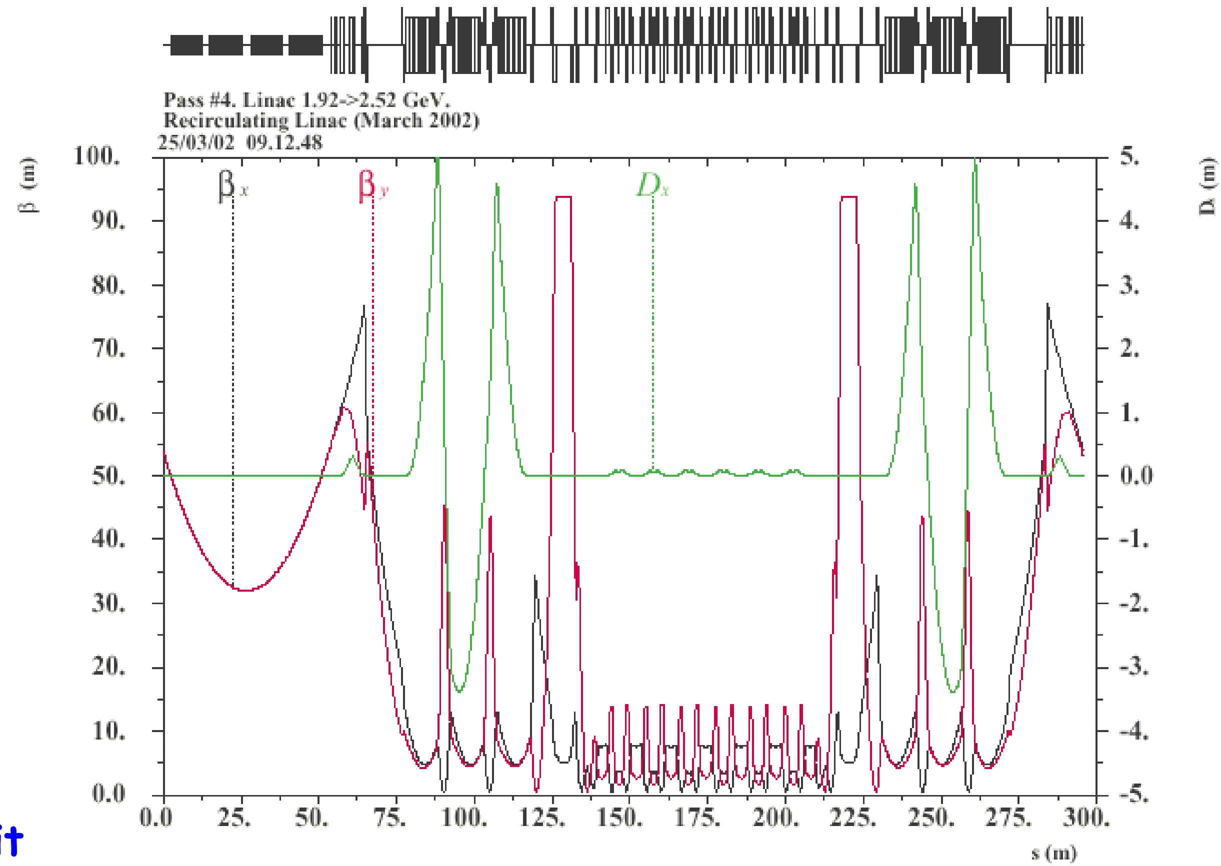
$$\sigma_{x-ray} \geq \frac{E_{beam}}{k_{rf}\, e\, U}\, \sigma_{y'}^{rf} \sqrt{1 + \left(\frac{\sigma_r}{\sigma_y}\right)^2}$$

Undulator x-ray pulse duration

$$\sigma_{x-ray} \geq \frac{E_{beam}}{k_{rf}\, e\, U}\, \sigma_{y'}^{rf} \sqrt{1 + \left(\frac{\sigma_{r'}}{\sigma_{y'}}\right)^2}$$



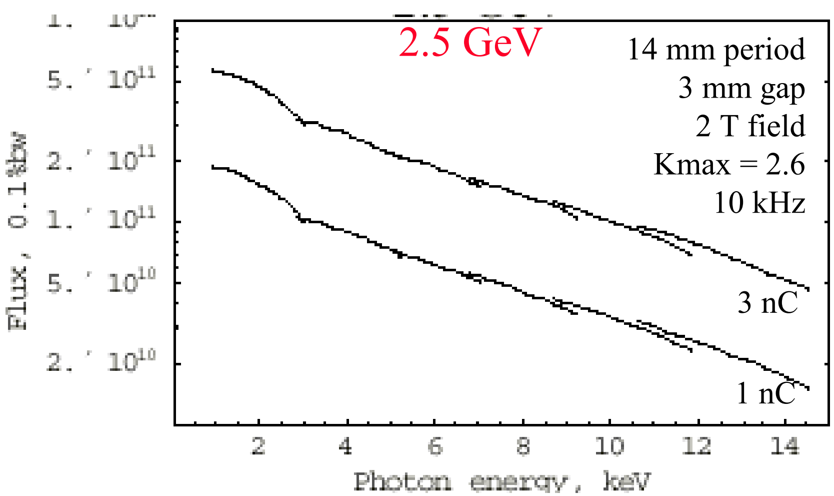
Lattice functions through final pass

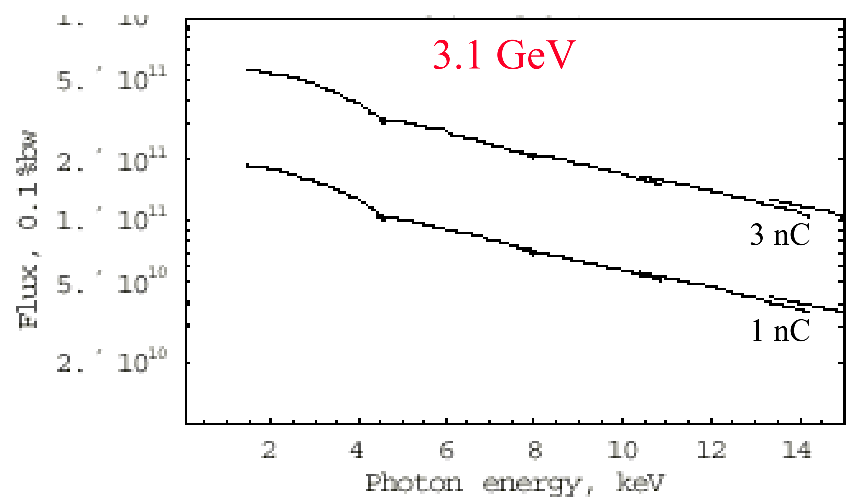


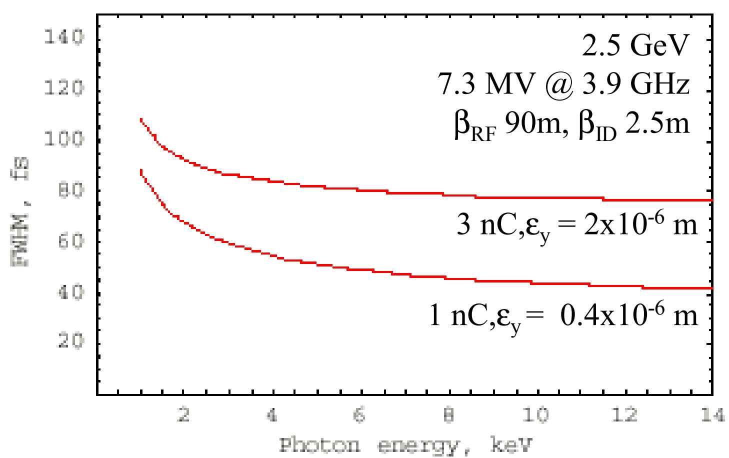
- **Short-wavelength photon limit**
  - X-ray pulse length limited by beam emittance
- **Long- wavelength photon limit**
  - X-ray pulse length limited by diffraction limit
    - Fixed optics, beam energy, deflecting RF system

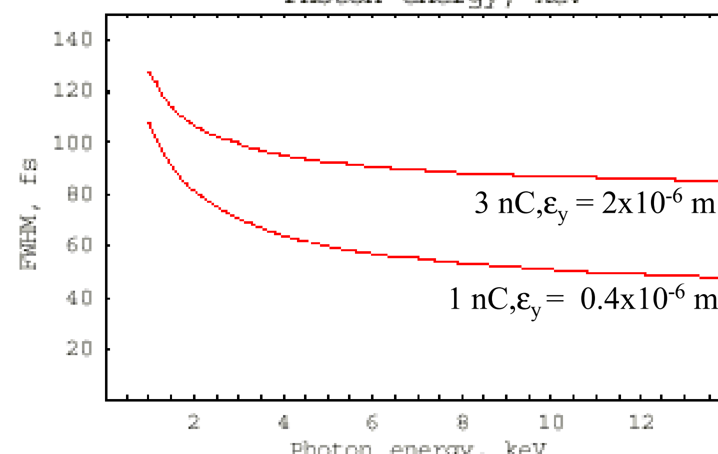
Baseline design for 2.5 GeV, 10 kHz rep rate
Upgrades to 3.1 GeV, higher repetition rate, higher charge

- **3.1 GeV with addition of cryomodule or operate at 25% higher gradient (25 MV/m)**
- **Average flux increased by repetition rate of RF gun & lasers**
- **Peak flux requirements more difficult to reconcile with pulse duration requirements**
  - **Emittance dominated by space charge effects in RF photocathode gun**



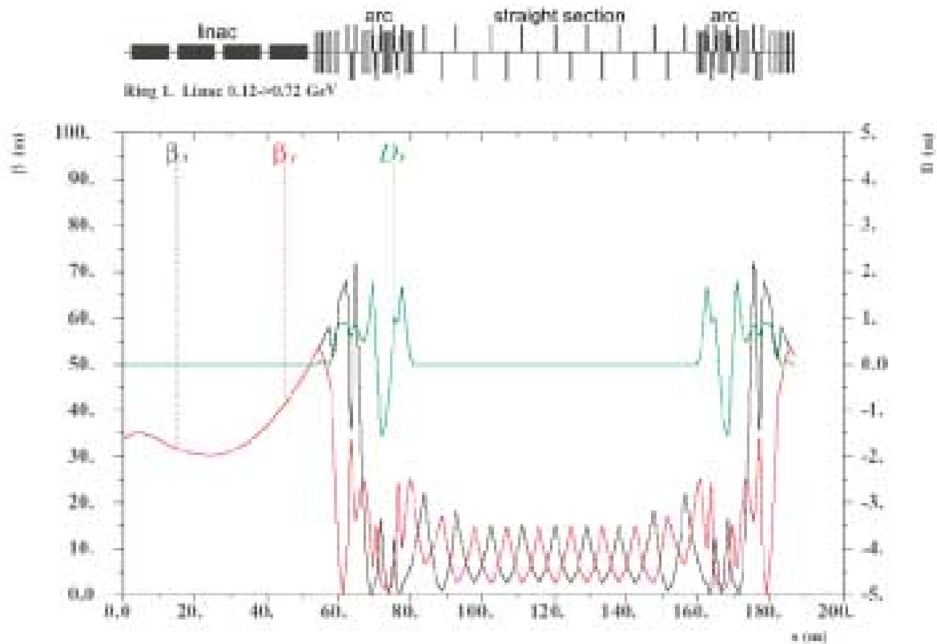


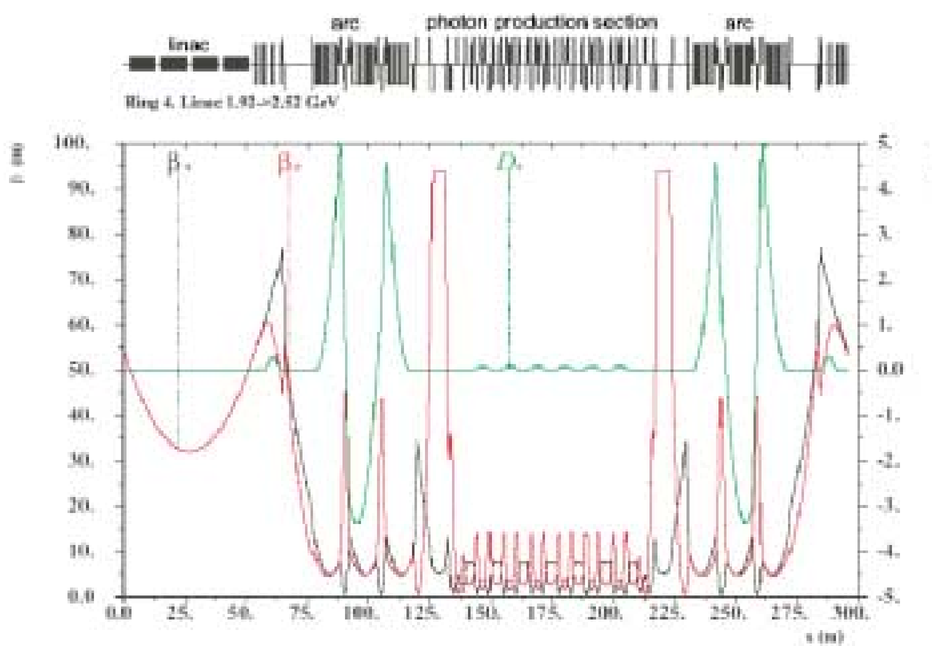




Lattice

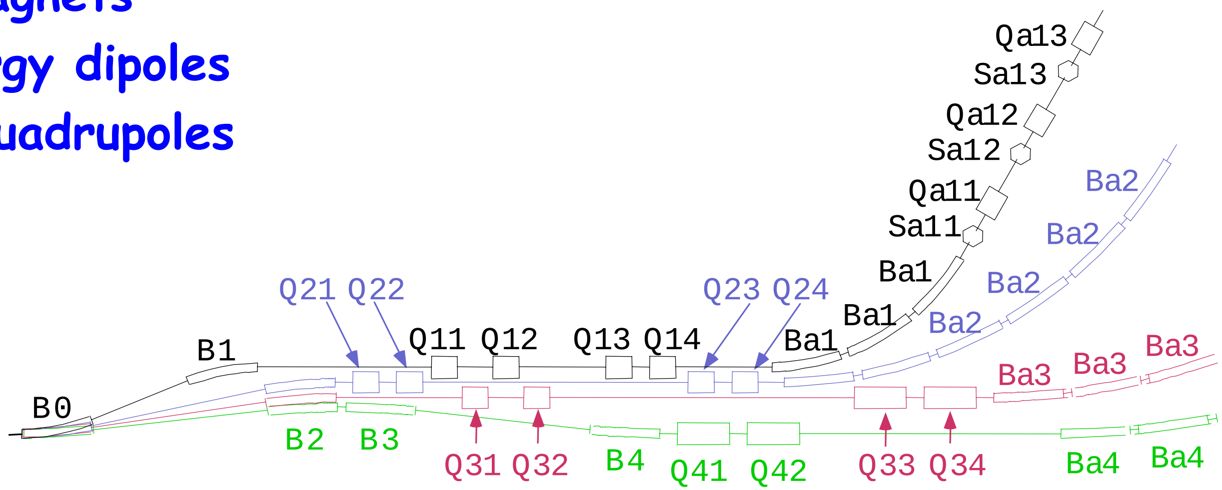
- Circumference of each pass adjusted to maintain uniform bunch spacing in linac for up to 12 MHz
  - 100 mA average in linac
- Bunch compression intwo stages
  - 20 ps – 10 ps after RF gun
  - 10 ps – 2 ps after injector linac
- Four passes through main linac
- Beam spreader separates different energy beams
- No focusing in linac
- Tune control in return straights
  - +- 0.5
- Normalized emittance
  - 20 mm-mrad Horizontal
  - 0.4 mm-mrad Vertical
- Momentum spread
  - 0.1 %

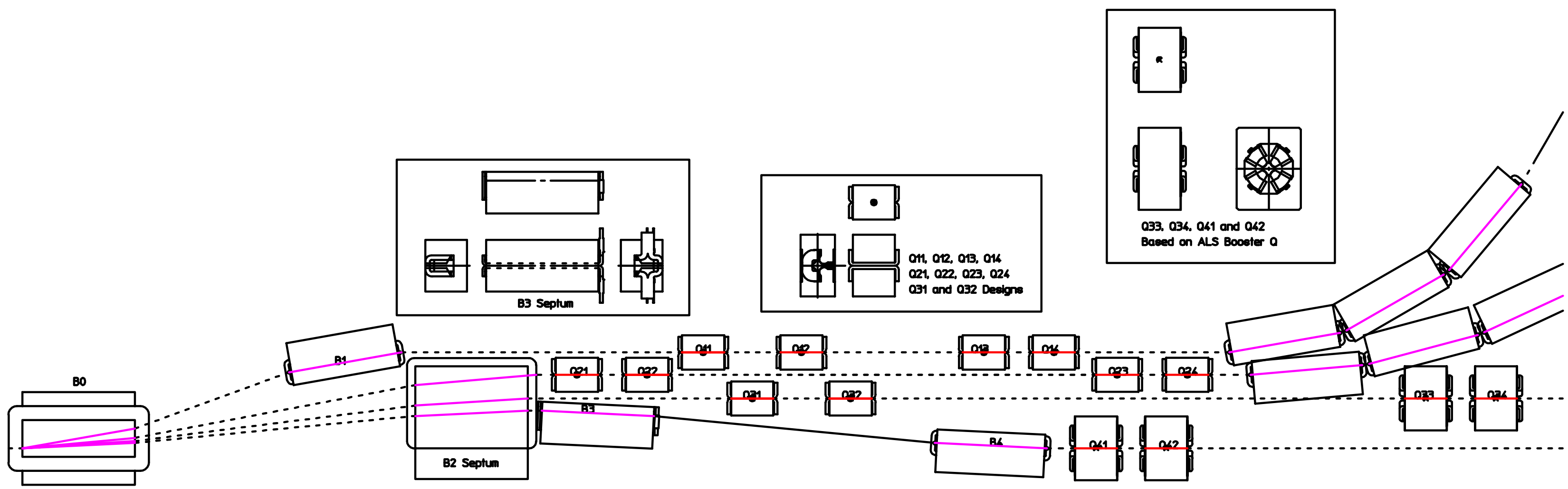




Compact beamline arrangement required to separate and combine beams of different energies

- **Septum magnets**
- **Multi-energy dipoles**
- **Compact quadrupoles**

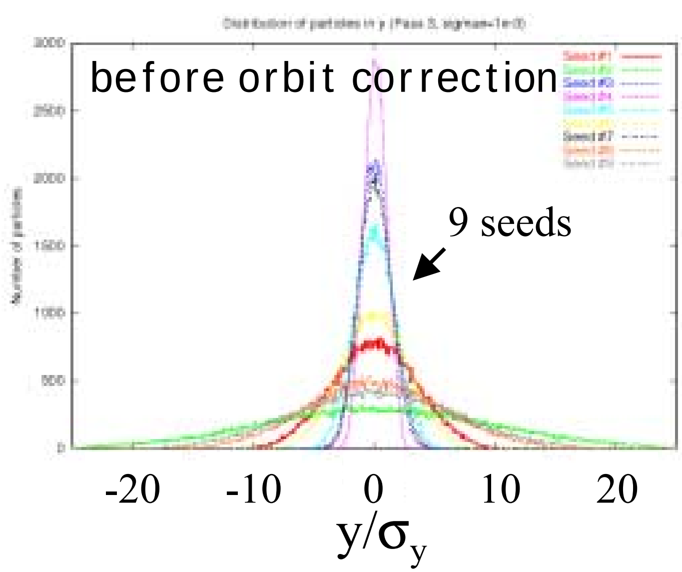


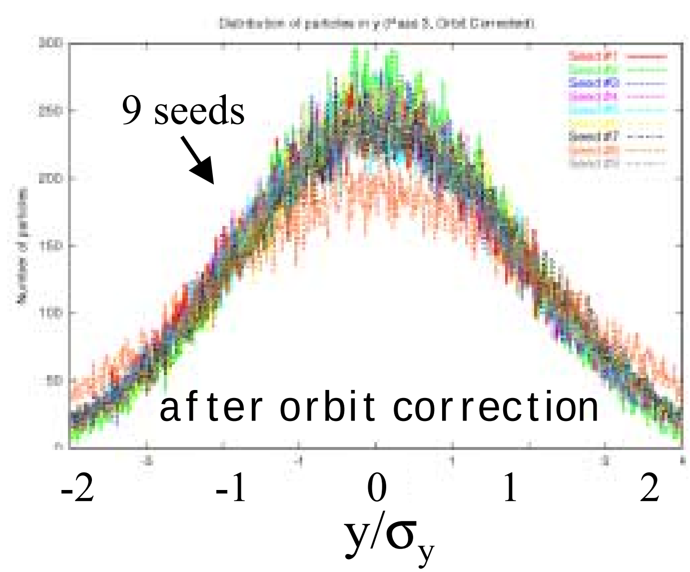


Lattice sensitivity

	Strength	Sextupole component	Transverse misalignment	Longitudinal misalignment	Roll
Dipole	1.0E-03	1e-4 at 3 cm	150 micron	1 mm	0.2 mrad
Quadrupole	1.0E-03	5e-4 at 5 cm	150 micron	1 mm	0.2 mrad
Sextupole	1.0E-03		150 micron	1 mm	0.2 mrad

Histograms of electron distribution after propagating arc #3 (9 seeds)

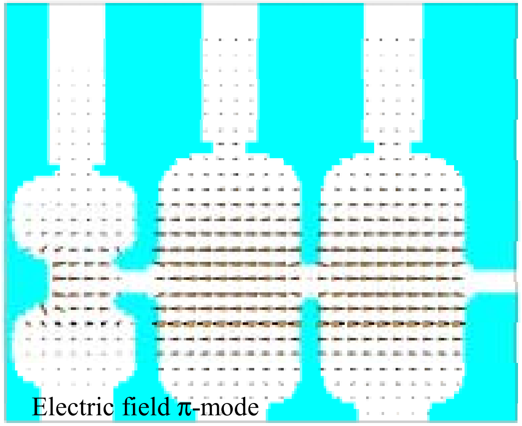


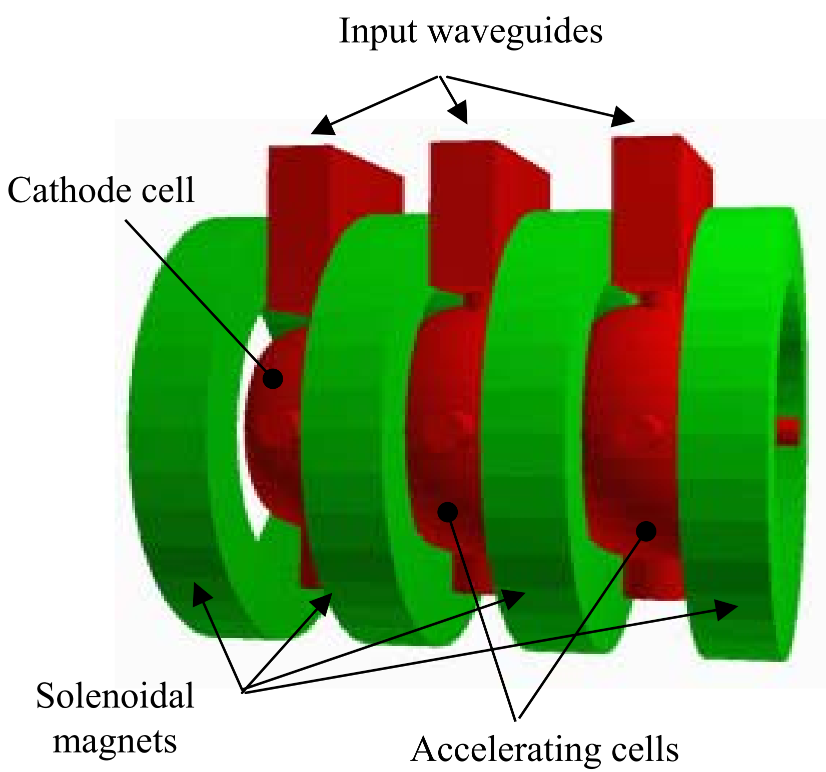


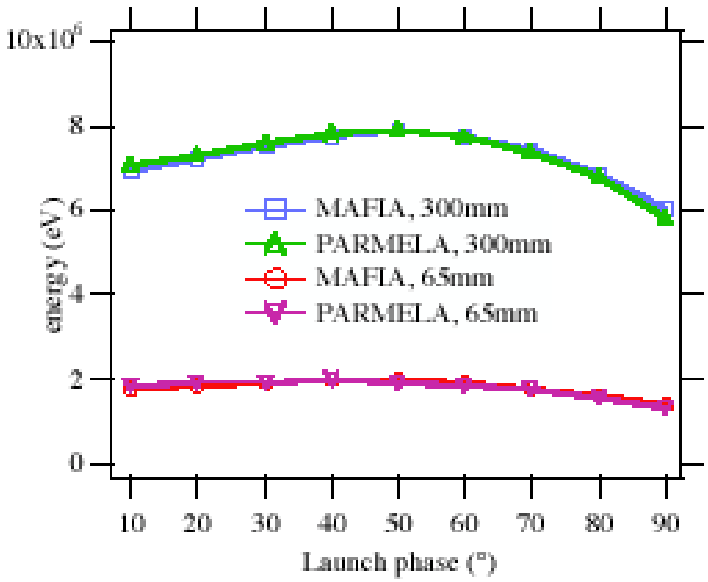
- **Orbit correction effective in preserving emittance**
  - **Beam based alignment**
- **Tracking code for particle tracking through entire lattice is being developed (*E. Forest, KEK*)**

RF gun development - key technology that drives pulse repetition rate up to 10-100 kHz

- 64 MV/m on cathode
- Three independently phased cells
- ~ 8 MeV output beam energy for three cells
  - Limit power dissipation <~ 100 W/cm^2

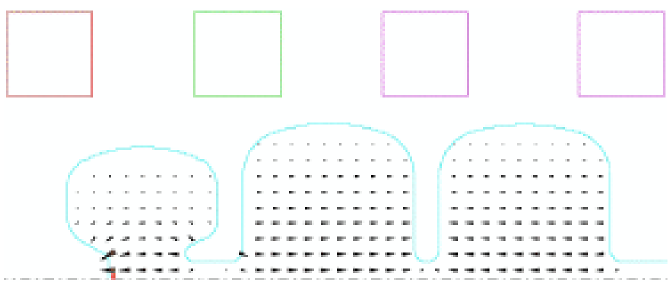


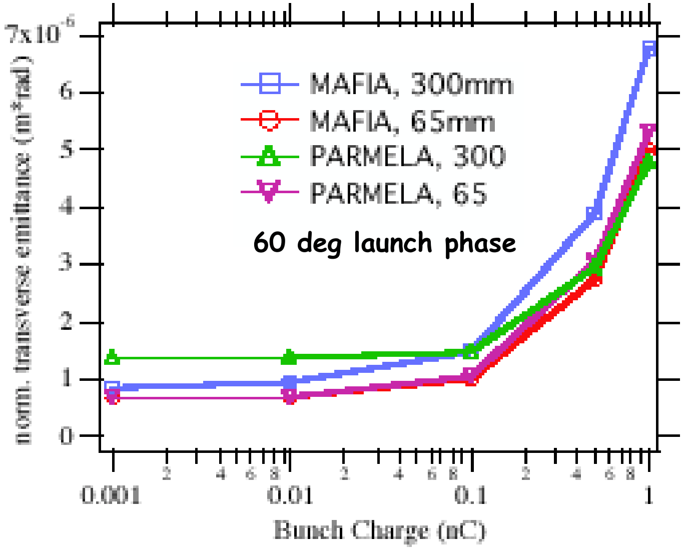


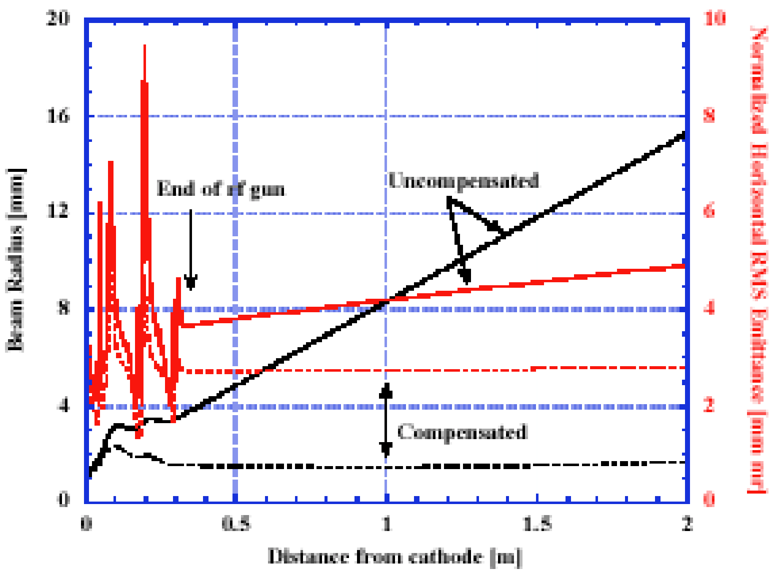


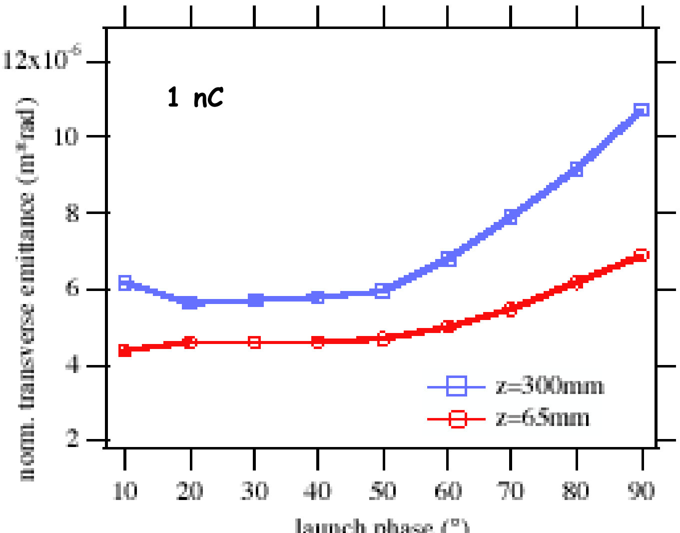
RF gun beam dynamics studies
HOMDYN, PARMELA, MAFIA

- 64 MV/m on cathode
- 43 MV/m cells 2&3, π mode
- 10 ps bunch length



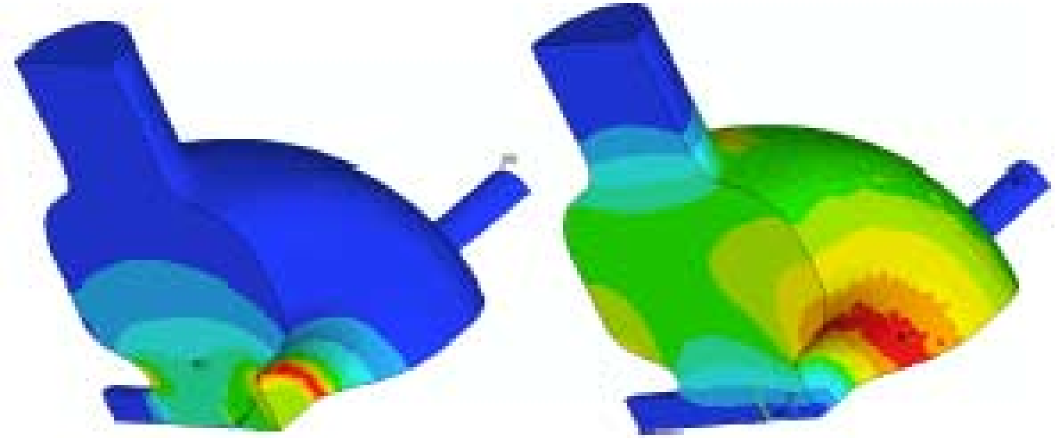




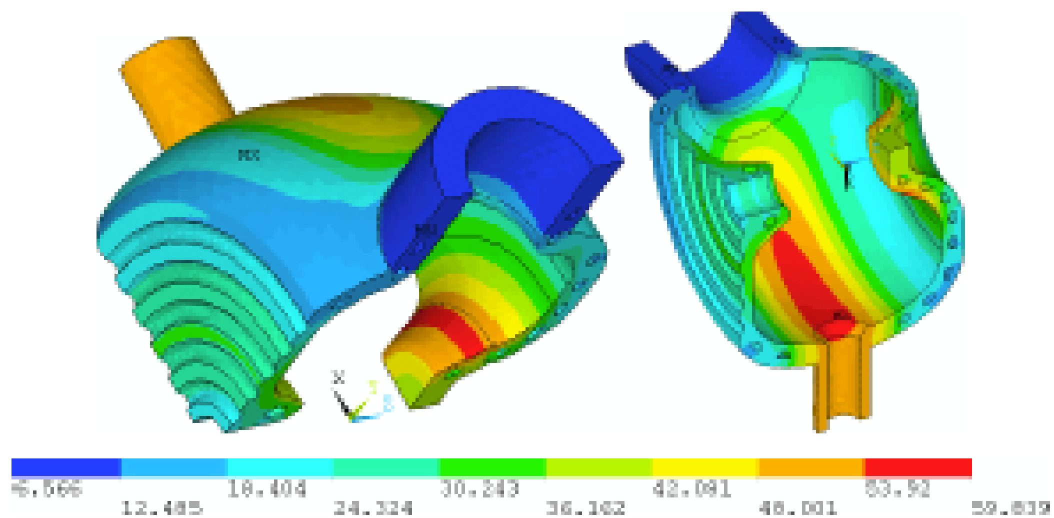


RF gun development
ANSYS model

	Gun cell	Cell 2 & 3
Frequency	1.3 GHz	1.3 GHz
Rep. rate	10 kHz	10 kHz
Duty factor	~5%	~5%
E_o	64 MV/m	43 MV/m
P_{peak}	581 kW	1550 kW
$P_{average}$	29 kW	77.5 kW
$P_{dens\ max}$	110 W/cm^2	107 W/cm^2



Surface electric and magnetic fields



Temperature above cooling water

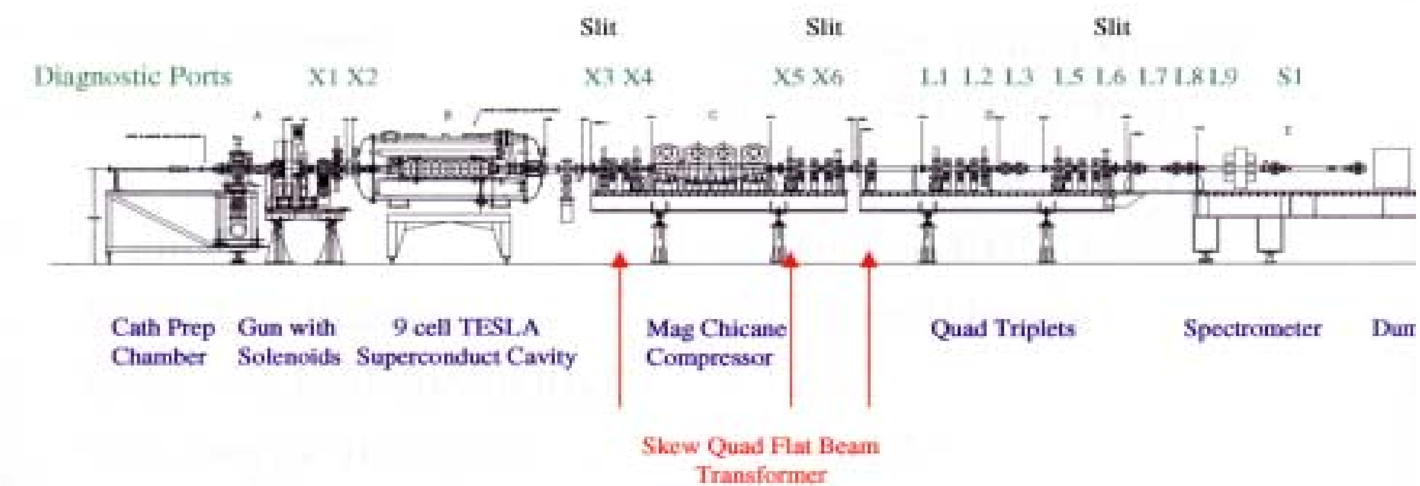
Flat electron beam production
Critical technique for producing fs-scale x-ray pulses

- **Flat beam transformation**
  - Generate circular cross-section beam from cathode in solenoidal magnetic field
  - Follow solenoid with quadrupole channel
    - Unit transform in x
    - $\pi/2$ phase advance in y
  - Quadrupole channel transforms beam shear developed on leaving solenoid into linear x,y distribution

$$\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \beta \\ 0 & 0 & 1/\beta & 0 \end{pmatrix} \begin{pmatrix} x_0 \\ k\,y_0 \\ y_0 \\ k\,x_0 \end{pmatrix} = \begin{pmatrix} x_0 \\ k\,y_0 \\ k\beta\,x_0 \\ 1/\beta\,y_0 \end{pmatrix} \xRightarrow{\beta = 1/k} \begin{pmatrix} x_0 \\ k\,y_0 \\ x_0 \\ k\,y_0 \end{pmatrix}$$

$$\text{solenoid},\ k = \frac{1}{2}\,\frac{B_z}{p/e}$$

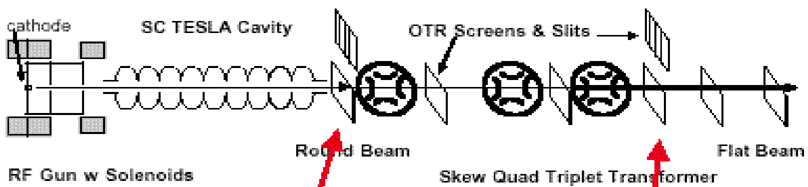
- **Fermilab/NICADD Photoinjector Laboratory (FNPL)**

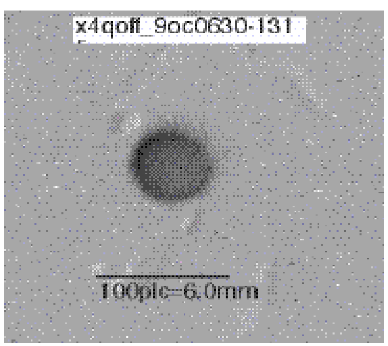


Flat electron beam production
Critical technique for producing fs-scale x-ray pulses

- **Fermilab/NICADD Photoinjector Laboratory (FNPL)**
  - Demonstrated large emittance ratio (50:1) with small emittance 0.9 mm-mrad @ 1 nC
    - Limit in vertical emittance will arise from thermal and space charge effects

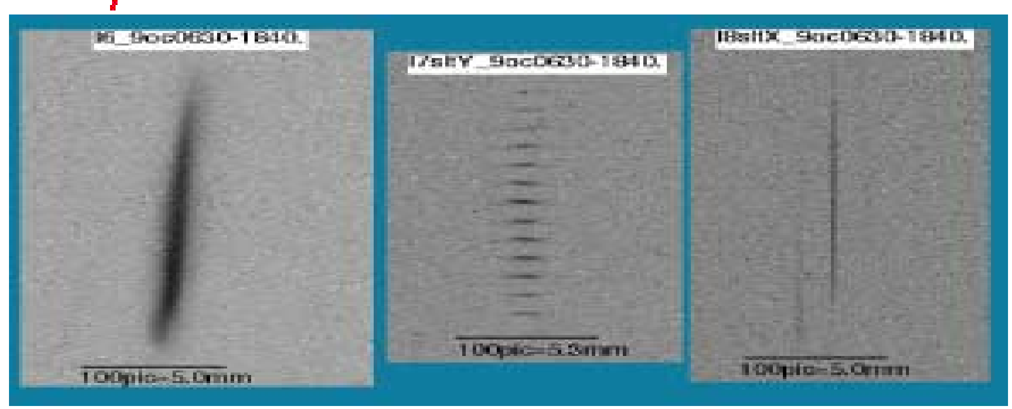
- **LBNL collaborating with Fermilab in flat-beam experiments and modeling**
  - Remote operations from Berkeley
  - Computer modeling to develop understanding of sensitivity, optimize performance
  - Develop hardware for operations improvements





Round beam image on fluorescent screen

Flat beam measurements

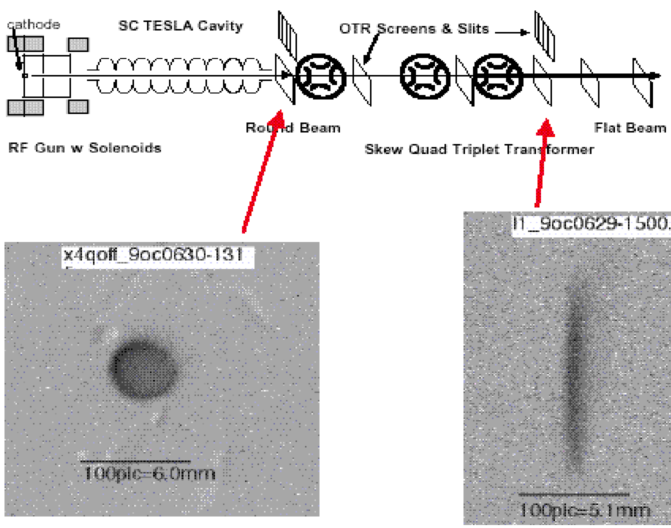


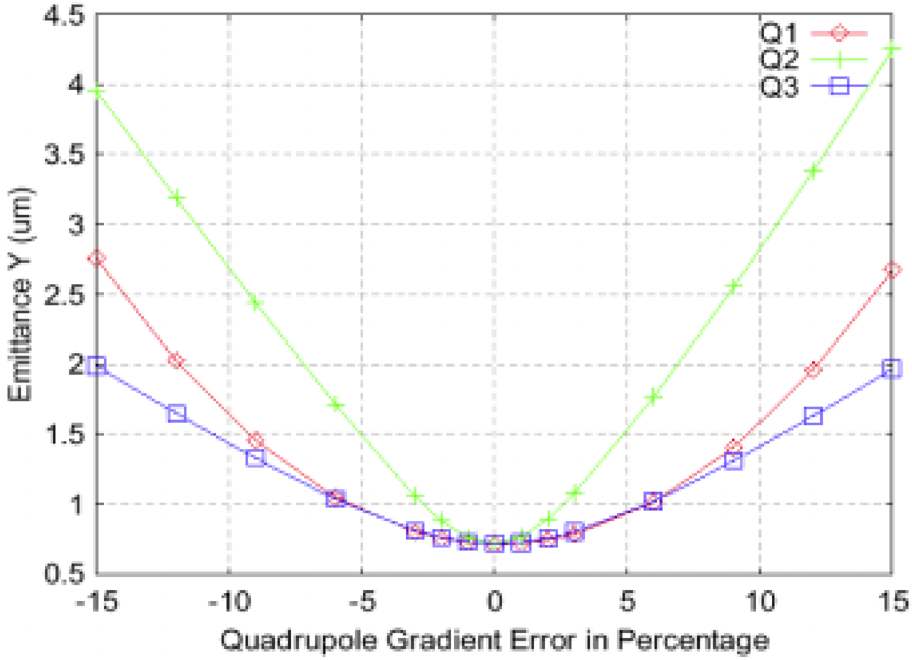
Flat beam image on fluorescent screen

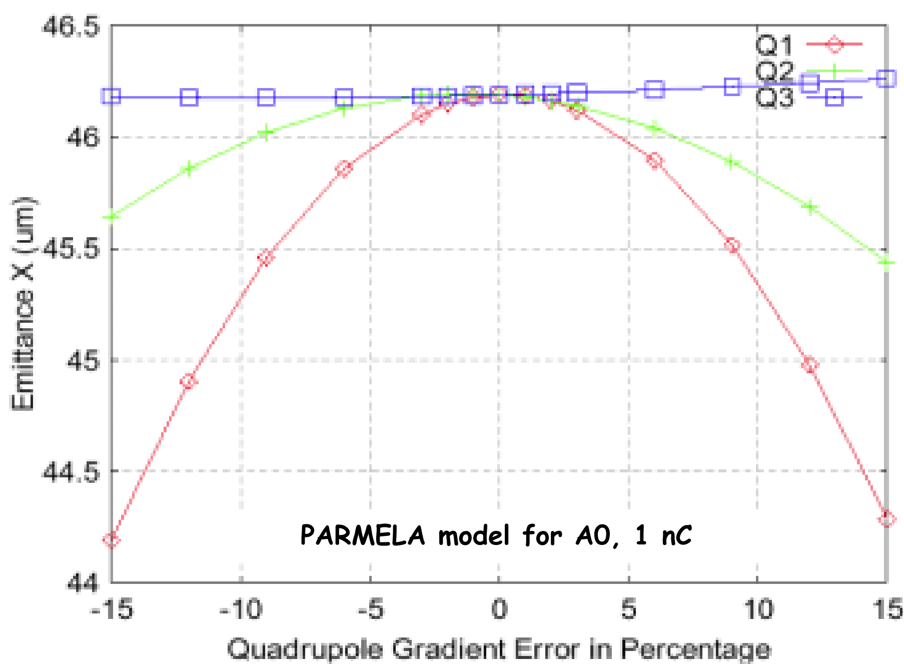
Beam image through slits for emittance measurement

Flat beam modeling

- Develop understanding of limitations and sensitivity of the flat-beam transformation
- Explore designs
  - Matching lattice parameters
  - Effects of RF focusing
  - Space charge
- Analytical model
  - Characterize circular beam in cylindrical modes
  - Transform to x – y modes
- PARMELA modeling

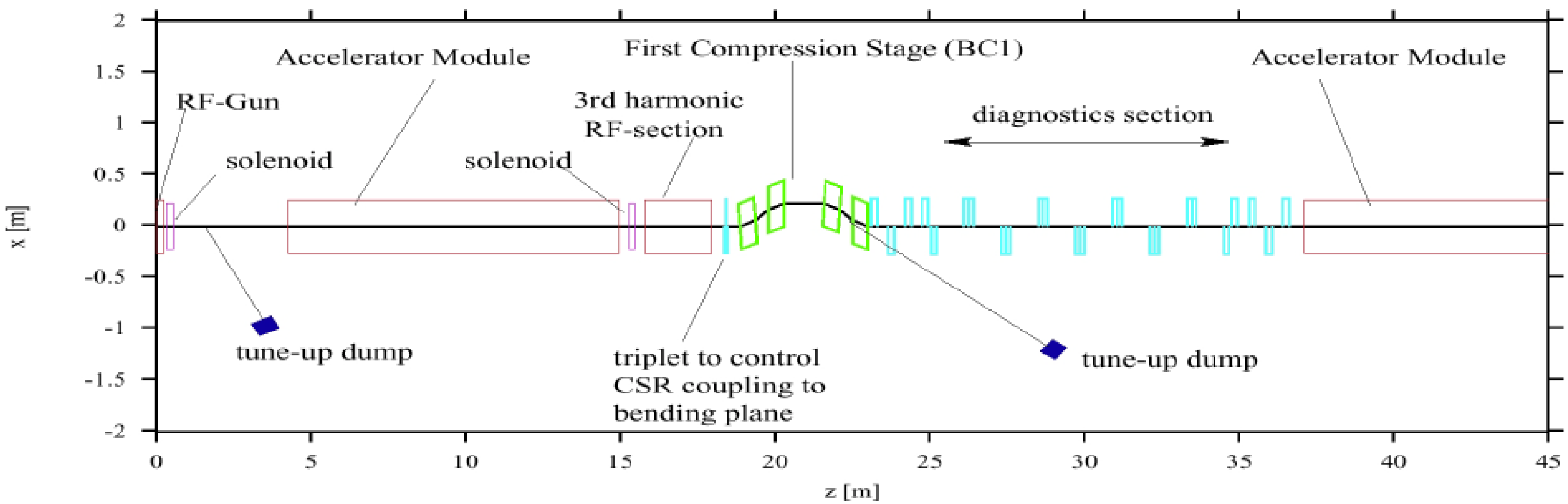






Pi3 proposal (TESLA TTF2)
A new RF photoinjector facility

- **Pi3 - photoinjector 3**
  - Development of existing RF photocathode injectors
  - Produce high brightness beams
    - Generate long bunch at gun to minimize space charge effects
    - Accelerate rapidly
    - Linearize longitudinal phase space using longitudinal harmonic cavity
    - Compress to short bunch



- **Proposal has similarities to Femtosource requirements**
  - We have joined the collaboration to produce a conceptual design report this year

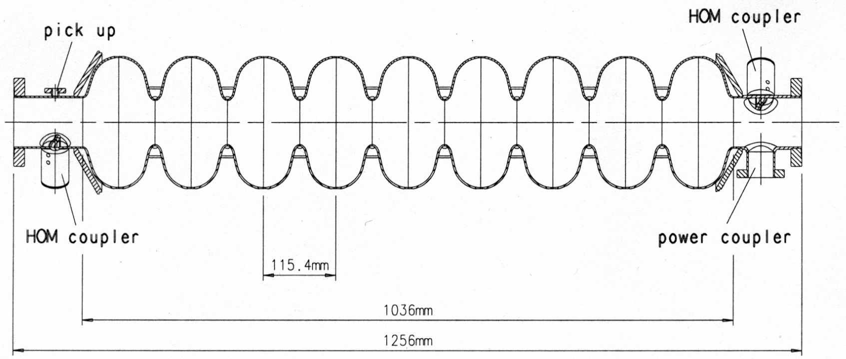
Superconducting RF structures - TESLA linac technology

- **Linacs use TESLA cryomodules**
  - **CW operations vs duty factor 10^{-2} (TESLA)**
  - **Low-level RF and cavity controls determine RF power requirement**
    - **External Q and detuning issues**

Parameters	TESLA	Fs Linac
E_{acc} [MV/m]	23.4	20
Operation mode	Pulsed	CW
Pulse length[ms]	1.37	CW
Repetition rate [Hz]	5	CW
Duty factor [%]	0.685	100
Power loss/cavity[W]	0.4	42
Beam current [mA]	9.5	0.04
Bandwidth [Hz]	520	65
Q_o	10^{10}	10^{10}
Q_{ext}	2.5×10^6	2×10^7
RF power/ cavity	1.85 MW	8 kW
Dynamic load at 2K (for 4 modules) [kW]	0.0125	1.3

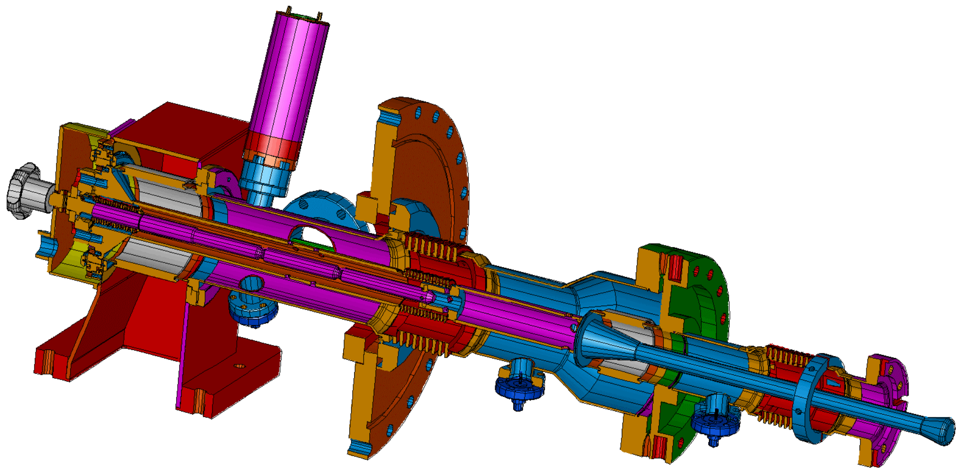
Figure 1.1.1: *The 9-cell niobium cavity for TESLA.*

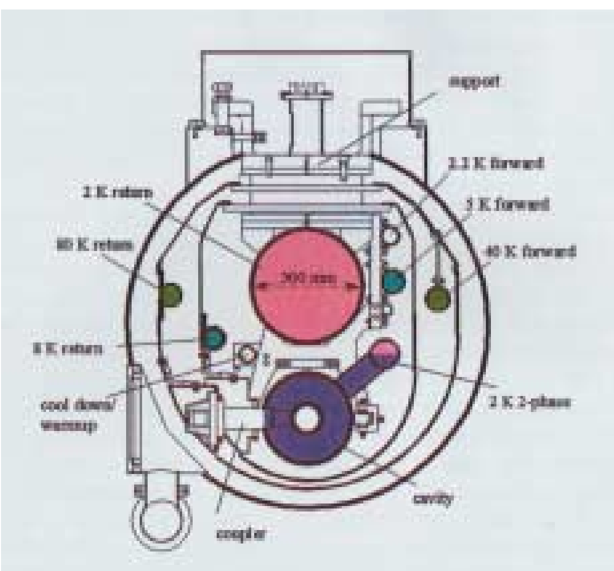
9-cell SC cavity for TESLA with E_{acc} = 23.4 MV/m



CW power considerations

- **Input coupler appears to be OK**
  - 10 – 20 kW reasonable
  - CW tests at Cornell to begin soon





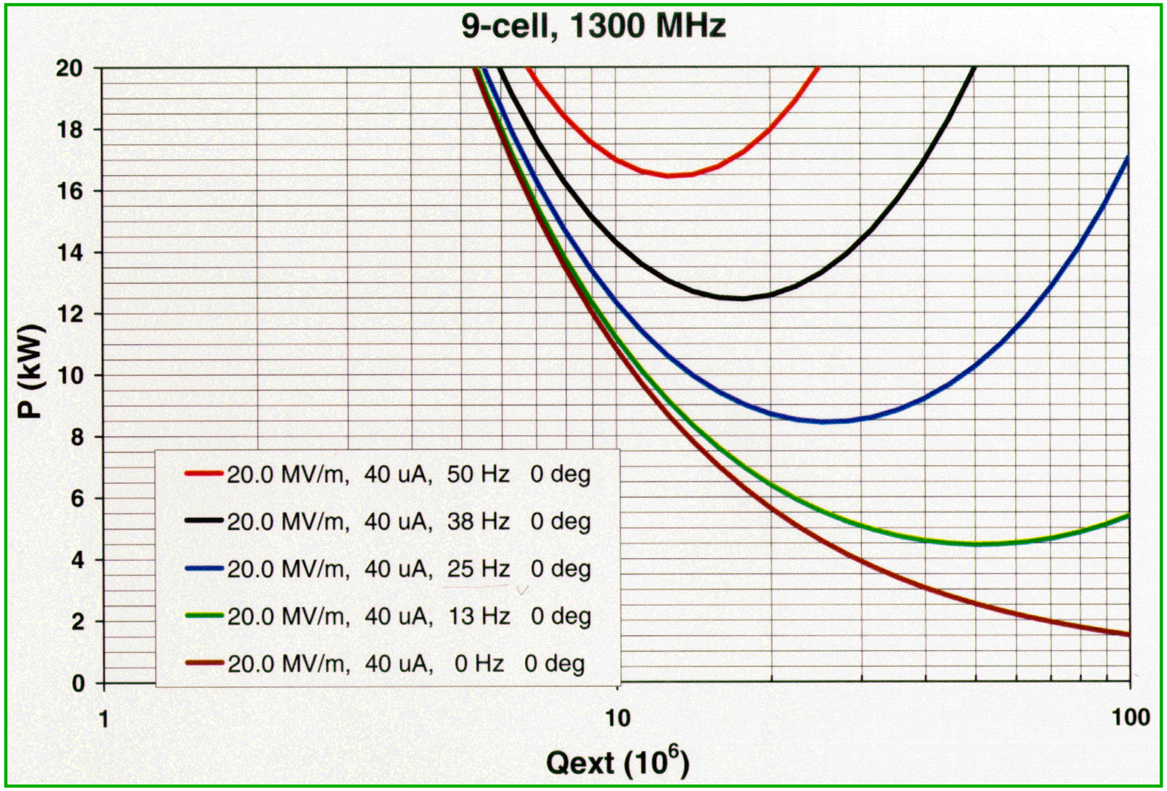
- **Exhaust He gas line adequate**
- **Cavity bath He supply needs to be improved**
  - Additional 2 – 3 connectors to liquid He supply
    - Increase thermal transport capabilities

Cavity coupling, external Q, power requirement

$$P_G = \frac{1}{4\beta_c}(1+\beta_c+b)^2 P_W ; \beta_c = \frac{Q_0}{Q_{ext}} ; b = \frac{P_{beam}}{P_W}$$

- +-25 Hz cavity detuning from microphonics
- Q_{ext} 2×10^7
- $\beta_c = 500$
- 8.5 kW/cavity

- 1.3 GHz RF power
  - 350 kW scrf
  - 260 kW RF gun
    - 610 kW total



J. Delayen, TJNAF

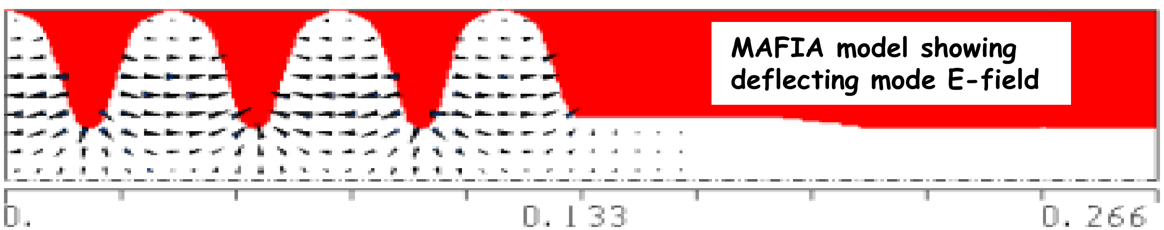
Each cavity is individually powered and controlled for amplitude and phase stability.

Superconducting deflecting cavities design produce head-tail deflection of electrons within bunch

- **Consider 7-cell cavities**
  - Deflecting voltage 8.5 MV @ 3.1 GeV
    - Requires seven 7-cell cavities

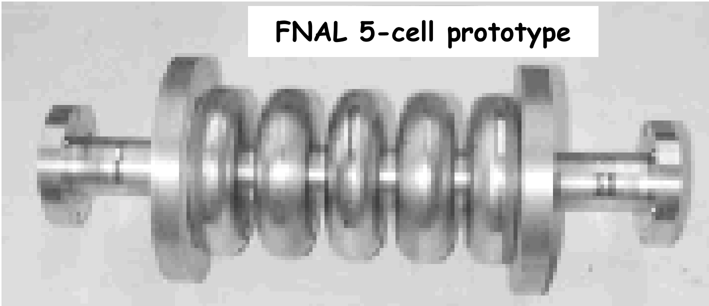
(R/Q)*	350	Ω
Q_0	2×10^9	
Active length/cavity	26.92	cm
Deflecting gradient	5	MV/m
Transverse voltage	1.346	MV
RF power loss at 2 K	2.6	Watts

Cavity frequency	3.9	GHz
Phase Advance per cell	180°	Degree
Cavity Equator Curvature	1.027	cm
Cavity Radius	4.795	cm
Cell length	3.846	cm
Iris Radius	1.500	cm
Beam pipe radius	1.500	cm
TM mode cut-off frequency	7.634	GHz
TE mode cut-off frequency	5.865	GHz



$$\frac{R}{Q} = \frac{\left| \int E_z(r = r_0)\, e^{jkz} dz \right|^2}{(k\, r_o)^2\, \omega U} \approx 50\ \Omega$$

- **3.9 GHz RF power**
  - 50 Hz bandwidth
    - 18 W per cavity
    - 126 W total

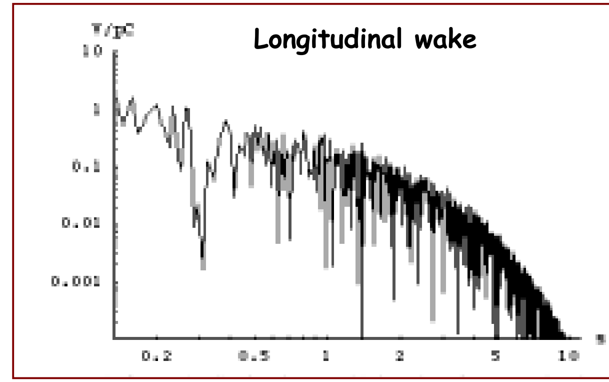


Superconducting deflecting cavities trap modes below operating frequency

- Lower order monopole modes dominate longitudinal wake

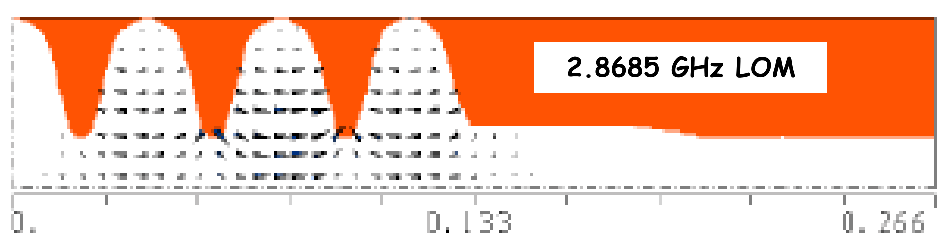
Frequency [GHz]	Q_0 [SC]	(R/Q) [Ω]	*k*-loss [V/pC]	R [MΩ]	V_{Induce} [MV]
2.8132	10^{10}	1	0.0038	8,656	0.0866
2.8208	10^{10}	1	0.0056	12,537	0.1254
2.8321	10^{10}	13	0.0597	134,150	1.3415
2.8453	10^{10}	10	0.0427	95,534	0.9553
2.8581	10^{10}	284	1.2742	2,838,100	28.3810
2.8685	10^{10}	411	1.8515	4,109,100	41.0913
2.8750	10^{10}	56	0.2546	563,800	5.6380
5.7836	10^{10}	0	0.0017	1,892	0.0189
5.8026	10^{10}	0	0.0002	265	0.0026
5.8348	10^{10}	4	0.0357	38,914	0.3891
5.8797	10^{10}	12	0.1105	119,610	1.1961
5.9343	10^{10}	5	0.0498	53,467	0.5347
5.9912	10^{10}	0	0.0002	164	0.0016
6.0377	10^{10}	0	0.0013	1,357	0.0136
6.6123	10^{10}	2	0.0233	22,481	0.2248
6.6135	10^{10}	0	0.0033	3,164	0.0316
6.7391	10^{10}	0	0.0010	926	0.0093
6.8025	10^{10}	2	0.0227	21,218	0.2122
6.8722	10^{10}	0	0.0037	3,390	0.0339
6.9377	10^{10}	0	0.0048	4,372	0.0437
7.0615	10^{10}	32	0.3507	316,200	3.1620
7.5036	10^{10}	10	0.1124	95,385	0.9538
7.5093	10^{10}	0	0.0014	1,214	0.0121
SUM			4.2147		84.4594

Dominant modes

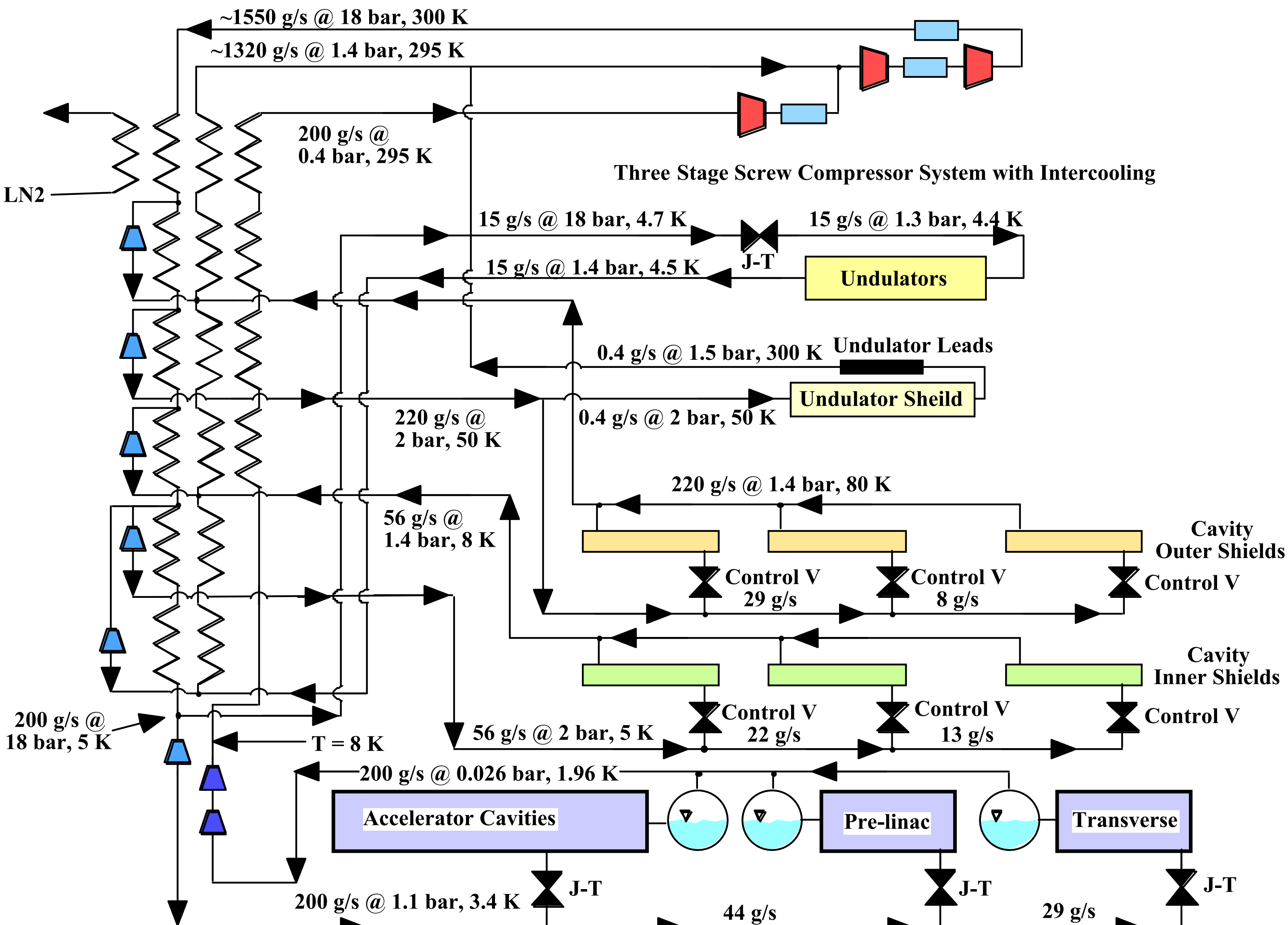


- LOM (lower order modes) produce energy spread
- Dominant modes must be damped

  Q < 10^6 (10 kHz bunch rate)
  - 10^{-4} energy spread
- Develop 3-D model to determine coupling to power coupler



Cryogenics systems



Refrigeration heat loads

	Acceleration Cavities	Linac Cavities	Transverse Cavities	Undulator Magnets	Total
	Refrigeration Loads in Circuits (W)				
Heat Load at 2.0 K	2817	272	534	---	3623
Heat Load at 4.5 K	---	---	---	158	158
Shield Load at 5 K	531	137	202	---	870
Shield Load at 50 K	23825	2615	924	407	27771

	Refrigeration at T (W)	Equivalent 4.5 K Refrigeration (W)
Cavity Refrigeration @ 2.0 K	3623	8390
Magnet Refrigeration @ 4.5 K	158	158
Shield Refrigeration @ 5 K	868	780
Shield Refrigeration @ 50 K	27771	2750

Design 4.5 K Refrigerator Size $\longrightarrow$ 12080

Cryogenics system power rating

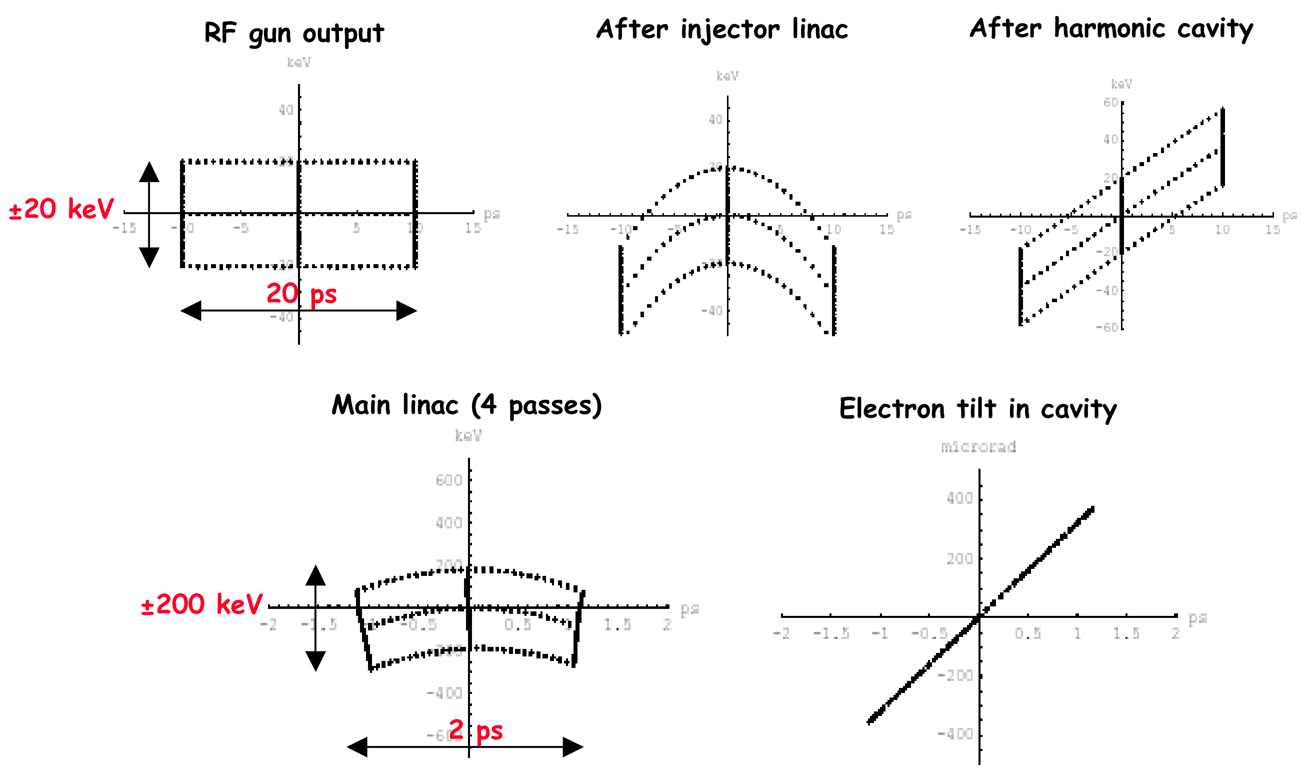
$$\eta = 0.155\, R(kW)^{0.137}$$

$$P_{in}(kW) = \text{Carnot}\ \ R(kW)/\eta$$

4.5 K Carnot Factor	65.7
Refrigerator Efficiency	0.218
4.5 K Refrigeration Delivered (kW)	12.08
Input Power to Refrigerator (kW)	3641
Power for Cooling and Switching (kW)	728
Total Input Power (kW)	4369

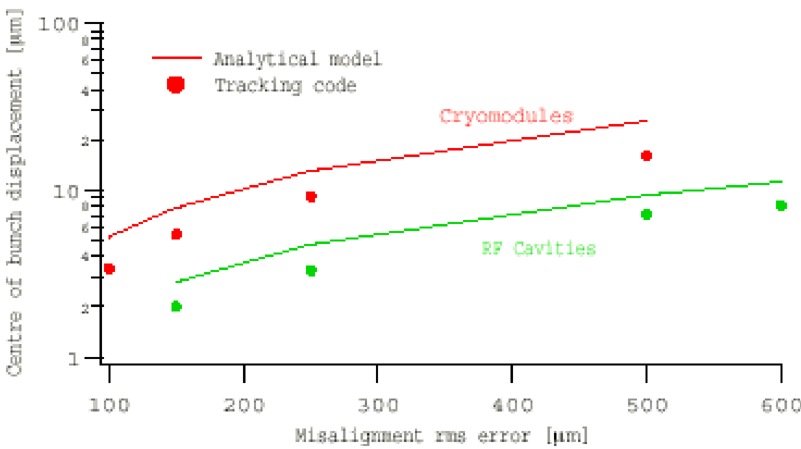
Longitudinal emittance control

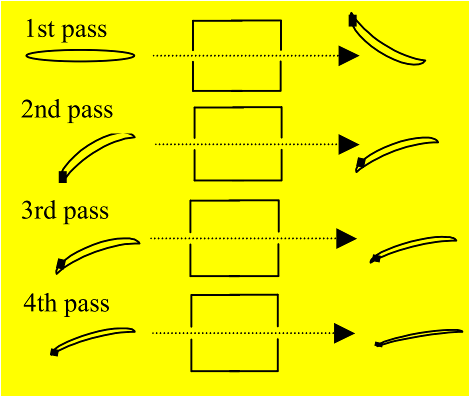
- Linearize phase space from injector using 3rd harmonic cavity
  - Energy spread in photon production section +- 200 keV
  - Bunch length ~ few picoseconds

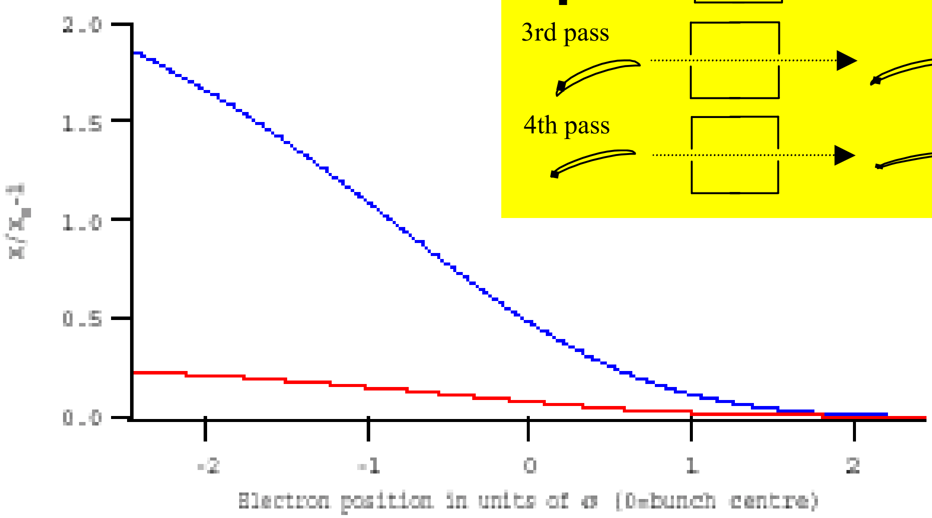


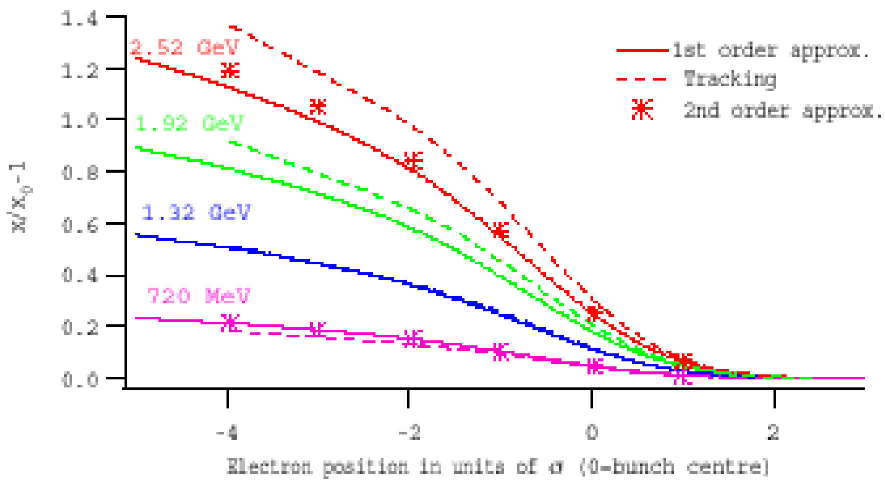
Cavity wakefields and BBU

- **TESLA cavity wakefields**
  - **Measured and computed cavity modes**
  - **BBU may be controlled in a recirculating linac**
    - **ß-phase advance π in first arc**
    - **Control of position offset through linac**
      - Displacement 50 - 100 µm









CSR and resistive wall

- **Coherent synchrotron radiation**
  - Electrons radiate coherently for

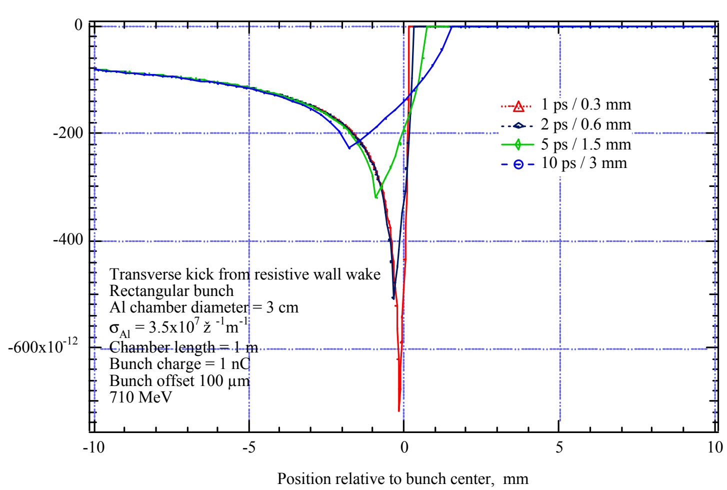
$$\lambda > 2\pi l_{bunch}$$

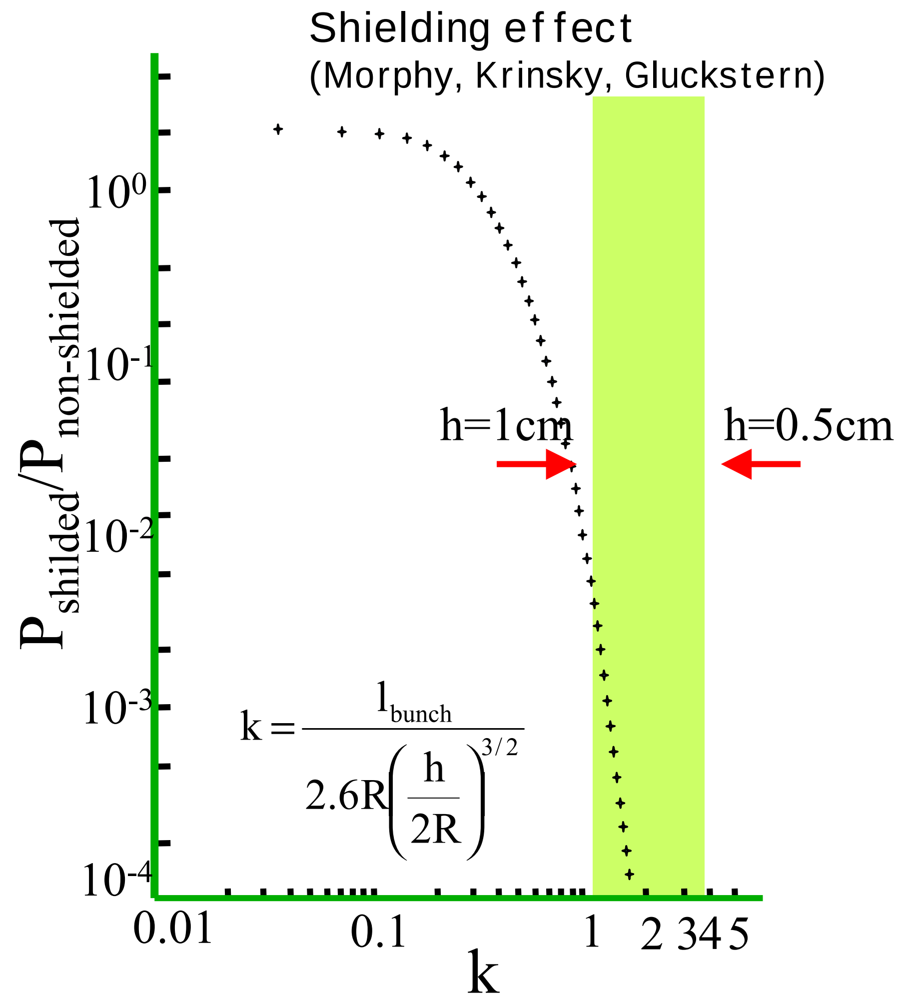
  - For rectangular bunch

$$\Delta E = -3^{3/2}\frac{N e^2 L_{mag}}{(l_{bunch})^{4/3} R^{2/3}}$$

  - 90 keV for 1 nC, 2 ps, 2T, 25 cm dipoles

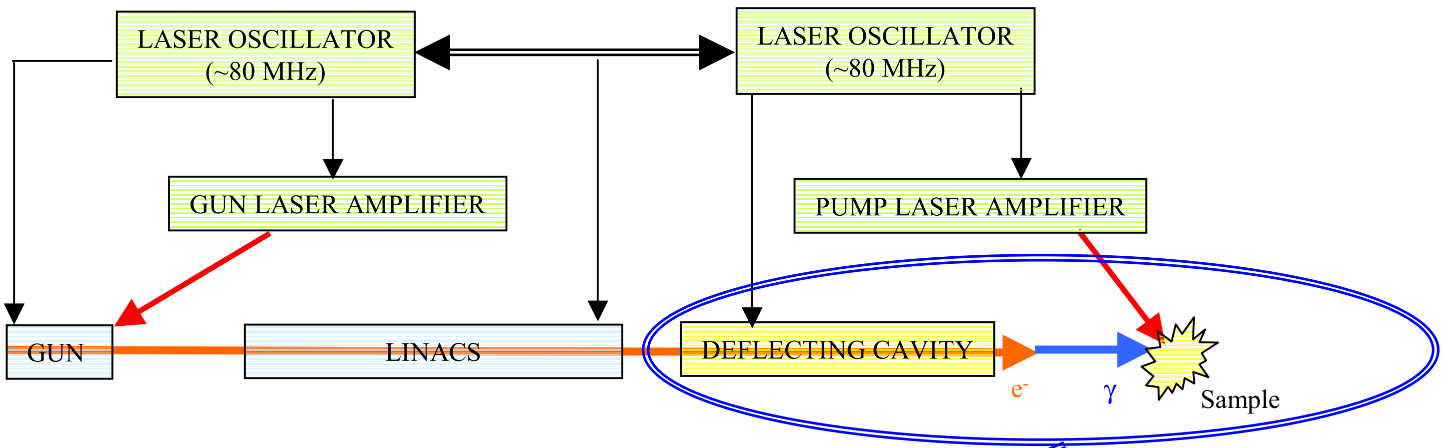
- **Resistive wall**
  - Vacuum chamber dimensions ≥ 1 cm
  - Emittance growth ~ few %



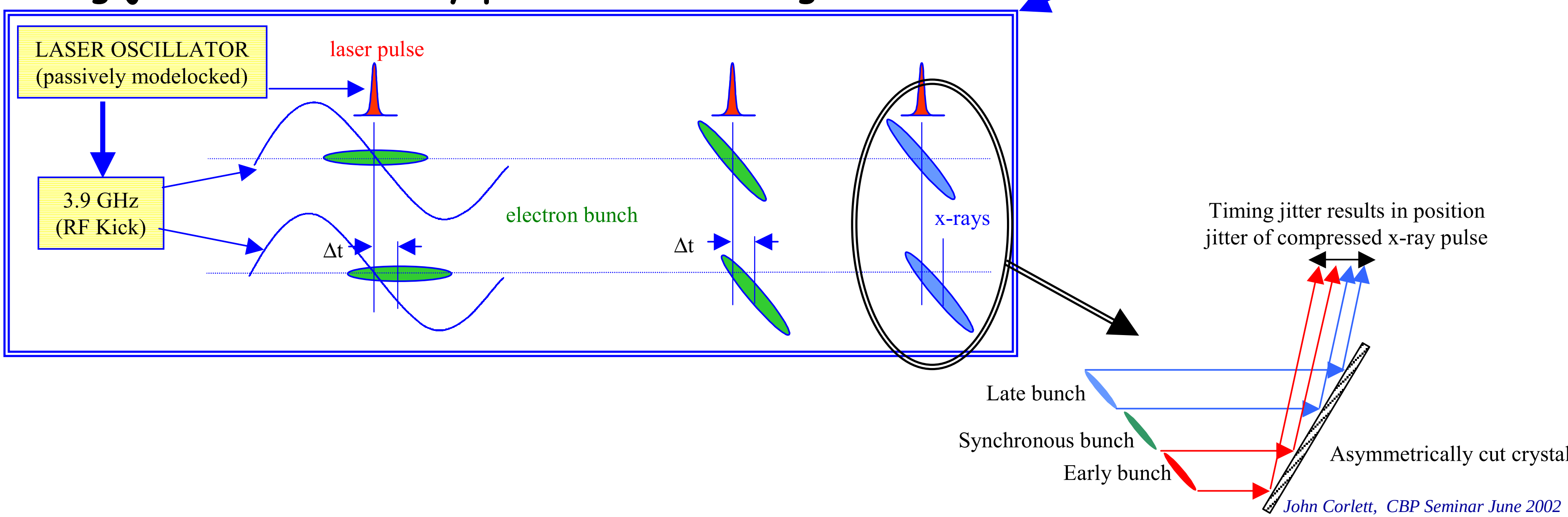


Scheme for synchronization of x-ray pulse and optical pump laser pulse

- Experimental lasers part of machine timing system

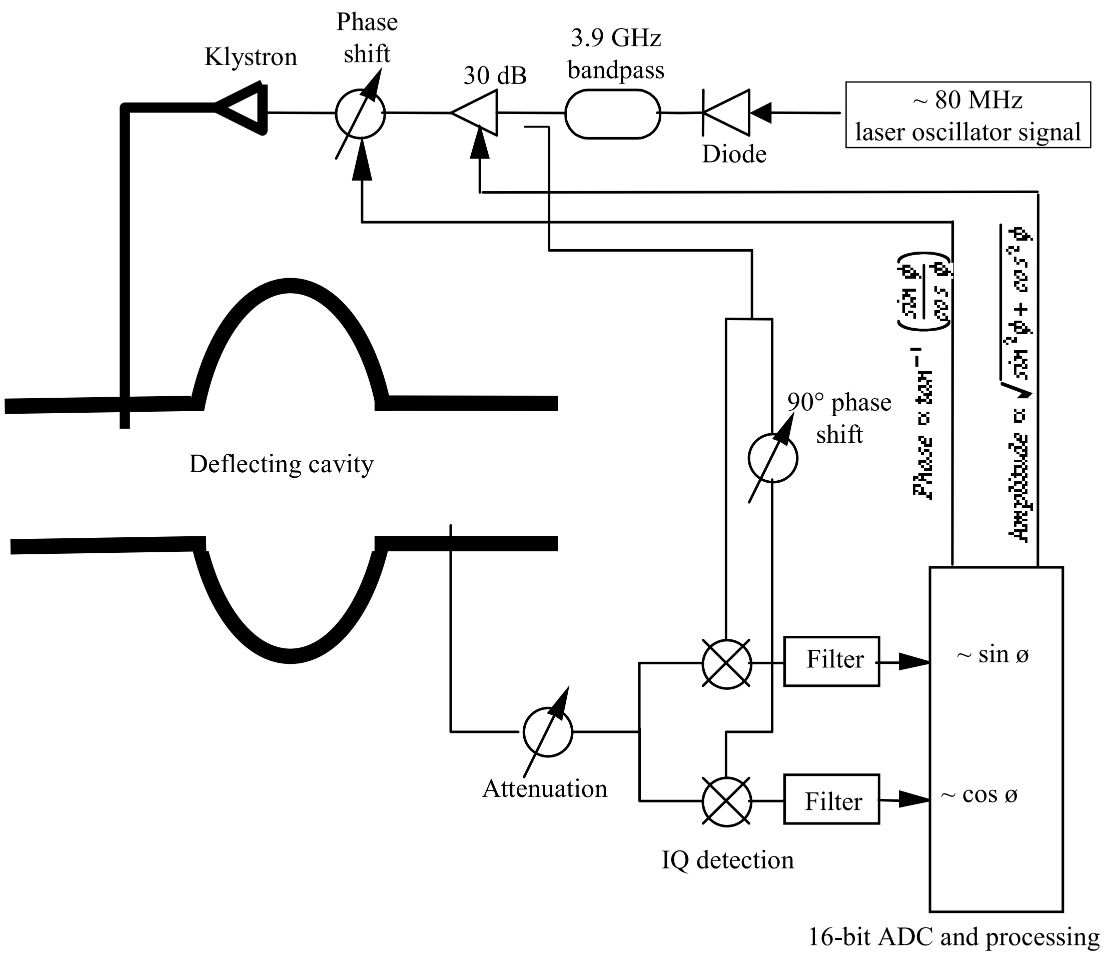


Timing jitter dominated by phase of deflecting cavities



Deflecting cavity phase and amplitude control

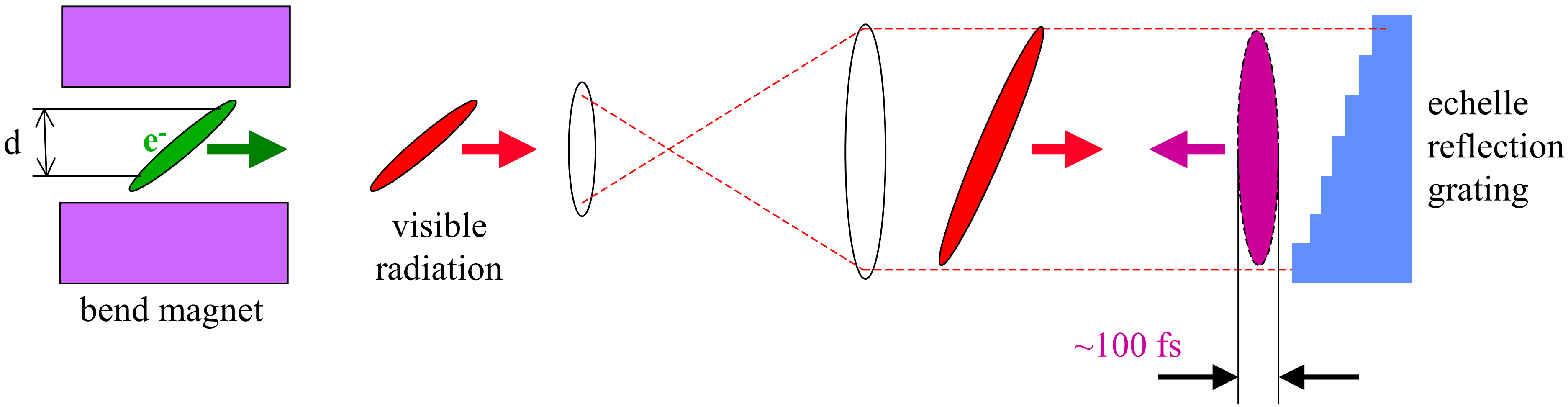
- X-ray pulse to optical probe laser pulse timing jitter dominated by phase of deflecting cavities



- Electronics
  - Resolution of 1 fs
  - $2.44\text{x}10^{-5}$ rad
  - 16-bit DAC
  - ~ 100 Hz bandwidth
    - Cavity itself defines system bandwidth
- Practical limitations
  - Laser amplifier drift
  - Thermal expansion of cables
  - Mechanical stability of cables and connectors
  - Cavity vibration (pickup with respect to cavity body)
    - 10 fs ≈ 3 µm

Scheme for synchronization of x-ray pulse and optical pump laser pulse using visible synchrotron radiaton

- Derive short optical pulse from dipole magnet
- Allows measurement of temporal drift of electron bunch with respect to laser pulse
  - ~ 100 fs pulse duration



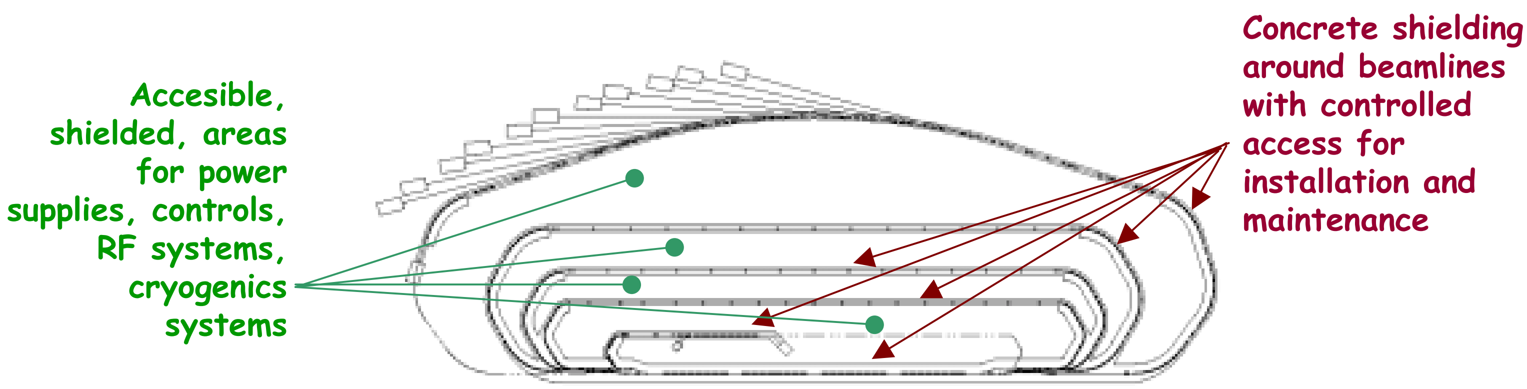
$$d \geq 50\sqrt{\sigma_{beam}^2 + \sigma_{diffraction}^2}$$

e-beam size (11 μm)

diffraction size at λ=600 nm (23μm)

Personnel and equipment protection

- **Requirements quite different from storage rings**
  - **25 kW continuously running injector into beam dump**
    - **Recirculation and energy recovery attractive above ~ 100 kW beam power**
  - **Must interlock electron beam generation to beam loss detectors**
    - **Can switch off electron beam via photocathode laser on pulse-to-pulse basis**
    - **Multiple systems interlock**
      - Bunch charge at beam dump
      - Distributed loss monitors alongside machine beampipe
      - Radiation monitors outside shield wall
      - Radiation monitors on experimental beamlines
- **Shielding around all beamlines in the machine**



  - **Allows location and access for equipment between different energy beamlines**
  - **Minimize roof shielding to allow use of second floor lab and office space**

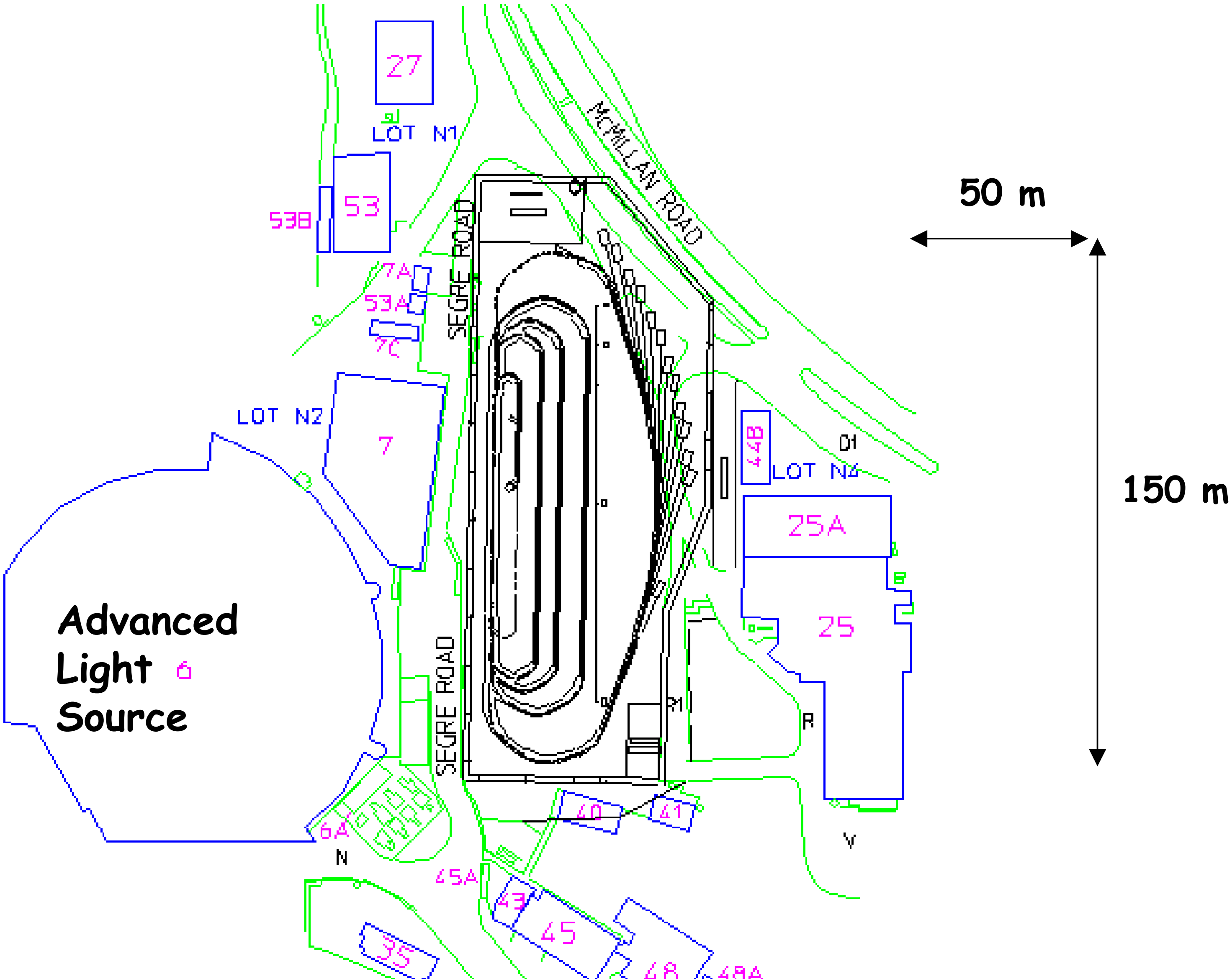
Conventional facilities

- Three representative facility buildings
  - 190,000 sq. ft. (17,600 sq. m.)
  - 160,000 sq. ft. (14,400 sq. m.)
  - 155,000 sq. ft. (14,900 sq. m.)
- Machine and experimental floor
  - Reinforced concrete slab
  - Pour-in-place shielding walls
- Office and laboratory space on second floor
- Second footprint most suitable for available sites at LBNL
  - ~ 110,000 sq. ft. first floor
  - ~ 50,000 sq. ft. second floor
- HVAC
  - Machine tunnel ± 0.5°C
- Electrical power
  - 5 MW machine
  - 4 MW experimental areas, office & lab space

Additional buildings

- Cryogenic plant
  - 10,200 sq. ft.
- Utility center
  - 4,000 sq. ft.
- Switching station
  - 3,600 sq. ft.

"Old Town" site with machine layout to scale
Synergies with ALS



Summary

- **Strong scientific interest in ultrafast dynamics studies using x-rays**
  - Workshop on New Opportunities in Ultrafast Science using X-rays
- **Machine feasibility outlined**
  - Machine Technical Advisory Committee Review
  - *"We believe the team is on the right track and has properly identified the key areas on which to focus"*
- **We will document the scientific case and machine feasibility study this year**
  - Need to put the Femtosource on BESAC agenda
- **Continue to develop science case**
  - Apply existing x-ray techniques to studies of ultrafast dynamics
- **Need to develop mastery of technologies outside present core competencies**
  - RF photocathode gun
  - Superconducting radiofrequency components and systems
  - Synchronization techniques
  - FEL technology